Physiology

Exhaustive and Practical

A Series of Practical Lectures Delivered from Day to Day by

John Martin Littlejohn

Professor of Physiology

In the American School of Osteopathy at Kirksville, MO

Especially adapted for Students of Osteopathy

1898

Dr. O. M. Strickland.

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KIRKSVILLE:
JOURNAL PRINTING COMPANY.
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PREFACE.

THE publication of "Physiology, Exhaustive and Practical" in its present form is due to a continued manifestation of interest in, and a high appreciation of the value of these lectures as delivered by Prof. Littlejohn, in his daily work.

Many students who, at first, thought them beneficial only for special preparation on the different subjects, now consider them more valuable for future reference and desire to preserve the same in a handsomely bound form and give them a permanent place in their libraries.

And to the end that these "nuggets of pure gold" may be properly treasured, I commend this volume to my fellow students, and would be glad to have their criticisms, as well as suggestions.

I desire to acknowledge valuable suggestions from numerous students and invaluable aid, in the preparation of this work, from Dr. J. M. Littlejohn.

I wish to thank the publishers for the extreme care they have exercised in the mechanical execution of the work.

H. R. BYNUM.

CONTENTS.

INTRODUCTION.

In beginning the study of Physiology we must always remember that all Science is one and that there is unity in Science that specialization cannot dispense with.

When we abstract we tend to narrowness and bigotry. Science literally means knowledge, and it covers the whole field of knowledge but it also implies exactness of knowledge based upon observation, experiment and classification.

Observation and experimentation furnish the basal facts which are reasoned about and reduced to unity and system. in the form of ideas; these ideas in turn forming the basis upon which science is systematically built up. Physiology is a part of science and a very essential part. Physiology literally means, from phusis and logos, reasoning about nature, in this case, limited to human nature, at least, in the field of human Physiology. Every form of life has a Physiology, so that Physiology really falls back upon Biology as the Primary Science. Biology is the Science of life in general. Physiology is the Science that reasons about the nature of life, its modes of activity and the actions of its organisms. In other words, it is the science of organized life. Morphology as distinguished from Physiology deals with the form and structure of living beings. Life, itself, from this standpoint, is that science of relations, physical, chemical and vital which gives us certain phenomena that we characterize as manifestations of vitality. This, of course, implies behind all phenomena the life principle.

Anatomy, Physiology and Pathology are the three great pillars upon which rests the Science of Medicine. The Science of Medicine is not limited to the prescription, and knowledge of Drugs or Physic; this is the degenerated idea of Medicine. The Science of Medicine deals with the preservation and prolongation of human life and with the curing of those abnormal conditions which tend to weaken or destroy life. Medicine in its history has followed several curative principles. Primitively associated with priestcraft, it consisted of certain ceremonial observances. Later it consisted of certain charms which the superstitious character of the people encouraged. To this day certain forms and incantations are believed to possess medicinal virtue. In the definition of the Science I have given, I think it is wide enough to cover Osteopathy, because I believe Osteopathy is a part of the Science of Medicine and Osteopathy should claim the word Medicine in its original sense, namely, that of healing. There are three great fields of knowledge in the Science of Medicine—Anatomy, Physiology and Pathology. Anatomy is the Science of organization or of the structure of the human system. Physiology is the science of organized life in its various functions. Pathology is the science which deals with abnormal conditions of human life. Symtomatology is the science which deals with results from the standpoint of Physiology and Pathology combined, with symptoms or signs of diseased conditions viewed from the standpoint of the expert physician who has a correct knowledge of Anatomy, Physiology and Pathology. To combat disease and consequently to prevent death we must have a thorough knowledge of these sciences. These represent the normal con ditions and also the abnormal conditions. To understand and meet the unhealthful conditions we must know the healthful and health-giving conditions and functions. Physiology forms the middle science in this trinity of sciences and is a most essential study in the field of Medicine. But there is a wider field in which Physiology figures. Physiology has not only a bearing upon Medicine but also upon Psychology and through Psychology upon the whole field of education. Physiology explains and largely accounts for Psychological conditions; for true Psychology is founded on Physiology. The mental states and activities are of value only as the illustrations of Psychological relations and conditions. The psychic conditions of life are brought out not alone in the field of education, in adaptations to study but also in the study and diagnosis of mental diseases, and many of the nervous diseases. The Physiology of the brain, spinal cord and of the entire nervous system is at the foundation of every true theory of life, whether we take it in regard to physical life, in its preservation, prolongation and its treatment under diseased conditions or in regard to mental life and even the higher moral and spiritual life.

A correct knowledge of Physiology applied in the field of Psychology has rendered obsolete older ideas and plans of education and has given rise to the modern natural school of education that has done so much to evolve didactic principles and plans for educating that is leading out and up the mind to the realms of knowledge rather than piling in the material into an already overcrowded mind. May we not look for the same reform in the field of medicine when Physiology is taught in all its bearings as it teaches the true functions of a differentiated human life consisting of a number of organs all of which are independent, and yet are united to form a single life. As we step into the higher field of Psycho-physiology, we realize the fact that mind is the ascendant power and that in a healthy physical life nothing less than a healthy mind can secure that vigorous condition of body so much desired by all. We realize also that while we treat purely bodily diseases we must not overlook the fact that Psycho-pathy partly discloses mental diseases and mind conditions without the removal of which it is impossible to cure bodily diseases. This wide field we believe is opened before Osteopathy and we think that our claim is not too great when we say in beginning this course of Physiology that Physiology is the gateway by which this immense field is to be entered. In its bearings upon the human life with all its functions we constantly remember that it is our purpose in teaching Physiology, to lead your minds up to that high standard of knowledge regarding Physiology which will qualify you to become efficient operators in the field of Osteopathy.

PHYSIOLOGY.

Physiology treats of organized and functional life. Human Physiology treats of the vital actions and functions of the various parts of the human system. In general it treats of the actions and the uses ot the various parts of the living body. Everything that has life has a physiology; hence, we have vegetable, animal comparative and human Physiology. Vegetable Physiology is brought out in the science of Botany. Animal Physiology is both comparative and human and embraces the whole animal kingdom. Comparative Physiology deals with the life of the inferior races of animals. Human Physiology teaches of the various organs of the human body. In order to understand Physiology, the construction and composition of the human body must be understood. The properties or relations of the human body are chemical, physical and vital. These relations when harmoniously sustained through a succession of time constitute life from a physiological standpoint. Life consists of the manifestations of certain phenomena, depending upon these three properties. One of these manifestations is activity back of which is the will and the mind. We have much to say of life, or vital activity, but the most that we know of it is its results. What life is and its exact position in relation to what we call the body is not known. All the parts of the body are united together by a wonderful sympathy and manifest united activity. The human body is an organism, that is, each part of the human body is both cause and effect in its relation to organism as a whole; this organism of the human body is differentiated into different parts or organs which discharge their own peculiar functions, all the different parts being united so as to constitute the single human body and the individual life. The three basic principles or elements of the human system are matter, motion and mind. These are called the trinity of operations in the human system. They are named in their order from the standpoint of result and of development from the standpoint of Science. We do not speak here of any first cause of these elements, we are not concerned with causation because that belongs to metaphysics. In Science we find these as facts and we deal with them as results. The lowest substratum of all development is matter; hence, Physics and Chemistry begin by discussing the fundamental properties of matter. Biology discusses the same properties in connection with life and the energy of life. Life, so far as known to us, exists solely as a manifestation of living matter the result of certain underlying causes, these causes manifesting themselves in activity through the human body and mind. Although living matter and lifeless matter are entirely distinct, yet they are closely related. Matter is constantly being taken into the body and transformed into the body substance by the functions of assimilation, absorption, etc. The living substance of the human body is the transmuted lifeless matter of food which has been taken into the body and has become animalized. The continuance of life depends upon the assimilation of this lifeless matter with the life substance of the body.

The theory of life in its continuance is that of the relation between living matter and lifeless matter and the great question is, how to accomplish this process of assimilation. The body is a living mould into which certain substances are cast to be assimilated into the system and the waste matters expelled. Prof. Huxley has said: "The living organism is in a constant state of turmoil in connection with material molecules constantly streaming into the body and out again." The second factor of life is motion. Matter is associated with motion because all life in matter is a form of motion. The living substance of the body is a compound of certain chemical elements. This living substance contains what are known as proteids. These compounds are composed of O, H, N, C, and sometimes at least, S and P. These proteids constitute the material substratum of the human body. Each of these elements has a peculiar characteristic; O has the power of combination, H has the power of mobility, N has the inertial power, so that in the complex compound the strongest properties are allied to constitute a human, material body. The material substratum of the human body is thus found to be proteids; these proteids affecting the chemical and mechanical processes of the human body.

There are not only material substances in the human body, but also power, capacity, function or energy. The living substance of the body has the power to manufacture new substances out of those substances taken into the body. This process of manufacturing, roughly speaking, represents the process by which the body organism renews itself for a continuance of life. The process of combustion goes on continuously producing heat which is converted into energy and motion. The bodily substance is constantly wasting away by this combustion process, and hence, needs constantly to be repaired. The repairs in the human system are effected by the characteristic development of the human body, known as intersusception, that is the power of taking in new particles and assimilating them to the bodily substance. In general there are three great functions in the development of the human system.

1st. Nutrition including assimilation or taking in and animalizing particles and nutrition proper which begins where assimilation stops.

2d. Muscular irritability. This is found in that vital property of the human body, called contractility. It is the power to respond to a stimulus.

3d. Reproduction. This is the power to separate a part of the corpuscle so as to form a new life.

There are two great centers of the body organism, the brain and the heart. The blood is life; it is bearer of the substances upon which vitality depends. The air is borne in the blood during the vitalizing process and the food substance is carried through the blood in those processes by which it is utilized as a tissue builder. In the bodily organism likewise, the nervous system maintains the control so that by the action and interaction of nerve and cell, the bodily health is sustained, the life is balanced and man becomes the highest of all creatures, a being of intelligence whose brain is the center of his life, from which go forth, impulses that regulate and control as well as direct the physical, mental and moral being.

The question of the division of Physiology is one which has been much discussed. It is based upon function. If we regard function as a means of existence, life itself consisting of the proper exercise of these functions. The old classification of functions was that of (1) vital, (2) animal and (3) natural functions. The best classification is that adopted by Aristotle, according to which they are arranged on

the basis of the object of the function fulfilled. According to Aristotle, there are two modes of existence. 1st. Internal or vegetative and 2d. external or animal, the former including the whole process of nutrition and the latter including locomotion. This idea was fully developed by Grimaud who speaks of the functions as two-fold. 1st. Internal taking place in the interior of the body, the chief function being digestion in connection with nutrition; and 2d. external in relation to external objects, the locomotive power directing all these external movements. One of the most complete divisions is that adopted by Richerand. This division is also based upon an object or end fulfilled. I. Functions in the individual life, (A) those which are subservient to the preservation of the individual by assimilating to his substance the food by which he is nourished. These include digestion, absorption, circulation, respiration, secretion and nutrition proper. (B) functions which tend to the preservation of the individual by establishing relations with external things and beings. This includes the nervous system and the special senses including also locomotion and animal mechanics. II. Functions subservient to the preservation of the species, including reproduction, embryology, changes of life, temperament and death.

The field of nature is divided, first, into inorganic substances ossessing the common property of matter. Second, into organic, or living beings, obeying particular laws while subject to the general laws of the Universe. Each of these orders has two forms. Inorganic is found first in simple elementary substances incapable of analysis, and second: Complex substance capable of analysis and decomposition.

Organic beings exist in the forms of vegetable and animal life. While we differentiate nature in this division we must remember the mutual dependence of these parts which demand simultaneous existance.

DIFFERENCE BETWEEN ORGANIC AND INORGANIC BEINGS—The latter are found to be very different from those endowed with life. 1st. In the homogeneous nature of their substance. 2d. In the complete independence of their particles, each of which has in its causes to account for its peculiar mode of existence. 3d. In the power of resisting decomposition; and 4th. In the absence of those powers which free organic bodies from the absolute dominion of the physical law. We cannot get a true idea of life without considering those bodies which are endowed with life as compared with those which have no life.

1st. Difference between organized and inorganized bodies is found in the homogenousness of the inorganic and the compound nature of the organic. If we break a block of marble we find no difference among the pieces except in size and shape. If we divide an animal or a vegetable we find different parts all of which have differences among themselves.

2d. Organic beings cannot live or exist in their natural condition unless solids and liquids enter into their composition. In the minerals the water or fluid which enters into or penetrates the substance does not form a part of it, except in so far as they enter into chemical composition.

3d. All the parts of the living body, animal or vegetable, have a natural tendency to a common object, the preservation of the individual and of the species. Each of the organs of the body performs its own function, and yet all the organs concur in the promotion of the same object and in development of the life in general. Life, then, would be the result of a series of concurring and harmonic actions. On the other hand, each part of the inorganic mass is independent of the other parts to which it is united by the force of affinity of aggregation.

4th, Among the animals and vegetables all the individuals of the same class seem to have been formed after the same model; their difference being slight. The forms of organized life, therefore, are more easily determined. That is, these forms are determined organically.

In minerals, the veins of the substance are never alike. For example: Crystals from similar substances often assume very different shapes.

5th. A powerful internal cause seems to arrange the different parts of animal and vegetable bodies so as to present a surface, more or less rounded. Minerals, on the other hand, often take their shape from external bodies, and when a special cause gives to them a special form, as in crystals, their surface is flat and angular.

6th. The most absolute distinction, that is, between the organized and inorganized, is that which depends upon growth and nourishment. Inorganic bodies grow only accretion, that is, by the accession of new layers to the outer surface, while the organic, by reason of their vital powers, receive into close combination, are penetrated and pervaded by the substance they assimilate. In plants and animals nutrition, used in its general sense, is the effect of the internal mechanism and their growth is development from within. In the minerals, growth is not properly a development, but an accession which goes on successively by the addition of new surface layers.

7th. Organic bodies spring from a germ, which at first was a part of another being from which it detached itself for the sake of its own development and growth. Inorganic bodies have no germ, but are made up of distinct parts brought together in combinations.

8th. Organized bodies alone can die. All these have a duration determined by their own nature, and this duration is not determined as in the case of minerals by bulk and density. If man has not the life of the oak, whose substance exceeds his in density, neither does he equal many of the animals, such as fishes, whose flesh is of an inferior consistency to his own.

DIFFERENCE BETWEEN ANIMAL AND VEGETABLE LIFE.

There are much fewer and less absolute differences between vegetable and animal life. There is, in fact, very little difference between a plant and a zoophyte. There is a much wider distance in their internal economy between man, who stands at the head of the animals, and the polypus, which stands at its lowest line, than there is between the polypus and the plant. There lies between organized bodies and inorganized bodies, a space which cannot be bridged, even by the Philosopher's lithophyte. At one end of the animal chain are found living beings, fixed like the plants on their birth spots, sensitive and contractile, like the plants reproduced from slips, yet we can see differences that are sufficiently marked between the animal and vegetable kingdoms.

1st. Difference: between Vegetable and Animal Kingdoms. Vegetables are more complex than minerals, less complex than animals. The proportions of solids to liquids is greater in vegetables, therefore, after death, they retain their form and size. Solids in man are about 1-6 of the body, and after putrefaction his body remains only a little dust and a slight skeleton, when the ground and air have extracted the liquid from his body. On the other hand, a tree is more than three parts of its substance solid wood. After it has been dead for ages, in buildings and other structures, it preserves its form and size, although by drying, it has lost its weight.

2nd Difference: The constituent principles of vegetables, as they are less in number, are also less diffusible. In fact azote (nitrogen), which is predominant in animal substances, is a gaseous and volatile principle, while carbon, the base of vegetable substance, is fixed and solid. This added to the smaller quantity of liquid, explains the long duration after death of the vegetable substances.

3rd Difference: There is one difference sufficient to distinguish between the animal and vegetable life. The zoophyte, fixed on his rocky habitation, cannot change his position and is confined to partial movements which are possessed also by certain plants. The result is that the zoophyte has not that sensitive unity so remarkable in animals and in man. The zoophyte, whose name indicates an animal plant, is totally separated from all beings of the vegetable kingdom by the existence of a cavity in which alimentary digestion is carried on as a process of absorption. From this animal up to man nutrition is carried on by two surfaces—the internal and external, especially the former; While in the plant nutrition, or rather the absorption of nutritive principles, is only on the external surface. Every animal considered as an abstraction has a nutritive tube, open at the extremities. The existence of a polypus is reduced to an act of nutrition, because its whole substance is used in forming an alimentary tube of which the soft surfaces are used in the absorption of substances brought into it. From the worm up to man the alimentary canal is a long tube, open at the two extremities, at first, in the lower forms only the length of the body, from the mouth to the anus; but, in the higher forms of life, this tube returns upon itself in complex folds between the two extremities. It is in the thickness of the walls of this tube between the mucous membrane that lines it internally and the skin with which the membrane is continuous that all the organs are placed which serve to transmit and modify the fluids, together with the nerves and muscles. In fact all that carries on life—that is the processes of life. As we rise from the white blooded animals to the red and cold blooded, and from these to the warm blooded, and finally to man, we find a gradual multiplication of organs contained within the walls of this canal. If we follow the same course downward—that is from the higher to the lower—we find the structure simplified till we reach the polypus, whose canal is so simple that it can be turned inside out without interfering with the proper discharge of functions. That shows that there is nothing on the internal side of the walls of that canal peculiar to the process of absorption as we find it in animal life. Thus it shows a very simple form of the alimentary canal. Man, therefore, and the whole animal kingdom carry about within them the supply of their subsistence and absorption by an internal surface which is their peculiar characteristic.

The digestive tube, that essential part of every animal, is the part of which the existence and action are the most independent of the concurrence of the other organs and to which the properties of life seem to adhere.

Haller, who has often been spoken of as the father of Physiology, states that in the heart we find irritability under the two-fold relation of lively and lasting, in the highest combination. This means the heart retains life longest. He gave the second place to the intestines, the stomach, the bladder, the uterus and the diaphragm. After this, that is, in the third place, all the muscles under the control of the will.

Richerand and Jurine have shown, however, that the intestines are always the last parts in which traces of life can be discovered. After the heart has ceased to beat and the rest of the body reduced to an inanimate mass, there are certain undulatory motions in the intestinal canal. If the intestinal tube is the ultimum moriens, that is, the last organ in which life lingers, then it is to it we ought to direct stimulation in cases of asphyxia. This connects the lower to the higher animal forms, for Jurine observed in the pulex monoculus that of all the parts of this little white blooded animal the intestines were the last to die. All animals are united in the possession of this canal, simple or complex.

LIFE.

We shall find life to be composed, at first, of a small number of phenomena as small as the apparatus to which life is entrusted. After extending these, as its organs or instruments are multiplied, and as the organism becomes more complex we reach the higher forms of life. The properties which characterize it at first are obscure, becoming more and more manifest as they increase in number as well as in developement and energy, the field of existence enlarging as we ascend from the lower beings to man—the most perfect being. This perfection simply means that living beings are possessed of more numerous organs, present greater results in life and multiply the acts of existence. In the Universe every being is perfect in itself, because each being is so constructed as perfectly to fulfil its purpose. In the plant which springs up, grows and dies each year we have a being whose existence is limited to the phenomena of nutrition and reproduction; a mechanism which consists of a multitude of vessels, straight or winding, through which, the sap is filtered and other fluids necessary to vegetation in the nutritive process. These fluids ascend generally from the roots, where materials are taken up to the higher parts of the organism, where what is left over from nutrition is evaporated through the leaves and the waste thrown off.

Two properties direct the action of this small number of functions—that is, as we find them in the plants—first a latent and feeble sensibility, by which each vessel is affected by the fluid with which it is brought into contact, and, 2nd. a slight contractility in virtue of which these vessels close, or dilate themselves under the fluid impressions so as to effect transmission and diffusion. The reproductive organs in the plant are characteristic. The male stamina bow themselves over the female pistil, shake over the stigma their fertilizing dust, and then die with the flower which is succeeded by the seed. This plant divided into many parts is reproduced also from slips, which proves this fact that each part is not absolutely dependent on each other part, and that each of the parts contains a set of organs necessary to life, and, therefore, can exist alone. This is due to the simpler organs—that is simpler as compared to the more complex—and to the diffusion of the properties of life in all parts, the phenomena of life being less connected than in the animals, especially in man.

Passing from the plant to the polypus, which forms the lowest link in the animal chain, we find a tube of a soft substance both sensitive and contractile, a life and organization as simple as that of a plant. The vessels which carry the liquid, the vessels called tracheæ, which give access to the air, cannot be distinctly traced in this homogeneous substance. There is no special organ of reproduction. The fluid oozes from the internal surface of the tube, first softens and then digests the aliments, the tube then spontaneously contracts and ejects the waste. The mutual dependence of parts is absolute, for, if it is cut to pieces, each piece becomes a new polypus, organized and living. These animals (gemmiparous) have the faculties of feeling and self-motion and are also capable of impressions.

Rising to the worms we have no longer animated substances, simply shaped into an alimentary canal; but parcels of muscular fibers, a vessel divided into a series of vesicles, which empty into one another by contractile movements, starting at the head and going to the tail, a spinal marrow composed of ganglia chains—that is different from the ganglia centers—and tracheæ analogous to the plant respiratories, and also in some of them we find gills. These all indicate perfect organization—these are the essential features that we find in this worm class of animals. The worm may also be divided into many pieces, each part becoming a separate organism, but there is a limit to this separation—that is, it is different from the polypus, any part cannot become separate and become a new organism. The crustaceous tribes, among them the lobster, give us a more complex organization in which we find distinct muscles, an articulated skeleton, movable in all its parts, a spinal marrow, a brain and aheart. The last two organs—the brain and the heart—place this form of life above that of the worm, because we find in this class a kind of intelligence and will impulses. These are based on the fact that these animals will follow smell—very distinctly, too, and flee from danger apprehended by the sense of vision.

There are also viscera for alimentary digestion, sensibility and contractility, subject to internal stimulus; Nerves and locomotive muscles which connect with the external world. In these animals there can be no separation of parts with the continuation of life, although a few parts may be cut off and still preserve the central foci of life.

Passing from the white blooded animals to the red and cold blooded such as fishes and reptiles. Life is more involved in organization and reproduction still further limited. Gills in these—in the fishes, of course—and lungs in others are added to the heart. The action of these chief organs, however, is less frequent. The serpent, for example, passes long winters torpid with cold, without air and without life motions. This is due to the capacity to suspend the admission of air and the capacity of breathing at very long intervals. The heart and other vessels of the fish feel and act within him without consciousness. Fish have senses, nerves and a brain, from which it knows what affects it; muscles by which it moves and adapts itself to surrounding environments.

Coming to the red and warm blooded animals, at the head of which we find man. We find this class of animals all alike, except in the less essential organs. All of them have vertebral columns, four limbs, the brain which exactly fills the cavity of the skull, a spinal marrow, nerves of two kinds, five senses, muscles partly voluntary and partly involuntary. Added to these organs a long digestive tube coiled upon itself, furnished at its opening with salival and masticatory instruments, with lymphatic glands, arteries and veins, a heart with two auricles and two ventricles, and lobular lungs. These are all the organs of life, and yet none of these organs live, except while they partake in the general action of the system and are under the influence of the heart. All of them die, or at least vanish from visual observation, when separated from the animal.

The human body consists of a collection of liquids and solids in the proportion of five to one, in six parts. This proportion is maintained throughout. The liquid, which constitutes the greatest weight of the body, existing before solids, for the embryo, which is at first in a gelatinous condition, may be considered a fluid. It is from the liquid that all the organs receive their nutriment to repair their waste. The solids formed from the liquids return to their former state; after having for a sufficient time formed a part of the animal they become decomposed by the nutritive process. Fluidity is thus essential to living matter, because the solids are uniformly formed from the liquids and eventually return to their former state. Solidity, therefore, is an accidental condition of organized living matter. Water forms a great part of this fluid and is the common vehicle of all the animal fluids. It contains saline substances in solution and even animal matter. We find this animal matter in the muscles in three different forms, gelatin, albumin and fibrin. The first of these substances, the gelatin solidified, forms the basis of all the organs of a white color, such as tendons, aponeuroses and cellular tissue and membranes.

2nd. Albumin exists abundantly in all the humours.

3rd. Fibrin of the blood forms the cement which is employed in repairing the waste of a system of organs,—the muscular system. Animal matter passes successively through these three forms, gelatin, albumin and fibrine, and these three different changes mark the successive changes in animal matter. The solid parts are formed into different systems, to each of which is ascribed a certain function. Limiting the expression organic system to a combination of parts which concur in the same usage as a means of existence or life, there is a difference between life and existence.

We have in all ten special functions—that is in the human body. Now we will mention these ten functions.

1st. The digestive apparatus, consisting of a canal extending from the mouth to the anus.

2d. The absorbent or lymphatic system, which consists of vessels and glands.

3d. The circulatory system, which is a combination of heart, arteries, veins, and capillaries.

4th. Respiratory System.

5th. Secretory or glandular system.

6th. Sensitive system, embracing the brain, the spinal marrow and the organs of sense.

7th. The muscular system, that of motion and locomotion, including muscles, tendons and apeneuroses.

8th. The osseous system, including bones, appendages, cartilages, ligaments, and synovial capsules,

9th. The vocal system.

10th. The sexual system—reproductive system.

Each of these systems contains in its structures several simple tissues. Those of the human subject being cellular tissue, nervous tissue, muscular tissue, besides the horny tissue which constitutes the basis of the epidermis, hair and nails.

These four substances may be considered as real organic elements, because we cannot succeed in converting anyone of these tissues into another. The idea of a simple elementary fiber which Haller, the Father of Physiology, sought in vain to discover, is purely imaginative. Bichat, on the other hand, exaggerated the multiplication of tissues when he concluded that there were twenty-one generating tissues. In the human organization we find the four constituent elements of tissue substance, the epithelial tissue, connective tissue, muscular tissue and nervous tissue. The epithelium is one of the simplest structures of the body. It consists of one or more layers of microscopic nucleated cells, called epithelial cells,

arranged so as to form membranes which line the free surfaces of the interior and exterior of the body, forming the free surfaces of the epidermis and of the mucous and serous membranes. Epithelial cells consist of a very fine cell wall and nucleus and nucleoli, and sometimes, also, other cell contents of liquid or granular matter. There are four varieties of these, that is, the epithelial.

1st. Squamous tesselated epithelial cells, flattish cells which overlie each other, as in the cuticle, and are placed side by side like pavement stones, as in the serous and synovial membranes and in the interior of the lymphatics and blood vessels.

2d. The granular or spheroidal epithelium cells. These are globular or rounded cells which line the interior of the compound glands, like the liver and gastric glands, which do the secretory work of the body.

3d. Ciliated or columnar epithelium cells which consist of conical shaped cells placed side by side, standing on their lower extremities. These cells line the stomach and the intestines. The upper part of the gastric follicles and the gland bladder.

4th. Ciliated epithelium cells which are generally of the cylindrical form, the free extremities of which are ciliated—that is lined with very fine cilia. These cells line the entire free surface of the respiratory tract, including all the air passages and tubes down to the air cells. We find a tesselated variety of the ciliated epithelium cells, which line the ventricles of the brain and the central canal of the spinal cord.

The second form of tissue, connective, cellular or areolar tissue consists of a mesh work, in which quantities of white fibrous tissue intermingle with a small quantity of yellow elastic tissues. This tissue is abundantly distributed throughout the body, forming a kind of a matrix which binds the tissues and the structures and the tissues together. It is very pliant and elastic. The white fibrous tissue consists of parallel bands of wavy fillaments like the fibers of a cord and is very tough, It is found in connective tissues, ligaments, tendons and fibrous membrane like the periosteum.

The yellow fibrous tissue consists of a very fine and well defined elastic fibers about 1·40,000 part of an inch in diameter. This forms the greater part of the elastic tissues, such as the vocal cords, the ligamenta subflava. This connective tissue also includes adipose tissue, which consists of fat cells distributed through the meshes of connective tissues. It also includes cartilages by which the ends of bones forming the movable joints are tipped. and also osseous tissue both in its cancellous form of slender fibers, of minute bars joined together like lattice work, and in its compact form, which consists of concentric rings of bone, arranged around a center, such as we find in the shafts of the long bones.

3d. Form of tissues—muscular tissue, is found in two forms, the smooth and unstriped muscular fiber, which form the chief constituent of the involuntary and hollow muscles as the alimentary canal, bladder, the coats of the arteries, excretory ducts, the great lymphatics and the trachea viris. Its chief characteristic is its power of contractility, under the influence of the will or nervous stimulation or chemical, mechanical and electrical irritation.

2d. Form is the striated muscular fiber which consists of a pale yellowish fiber, each fiber having a sheath and each fiber being capable of division into fibrillae. These fibrillae form bundles, the smaller bundle being called the fasciculi and the sheath of connective tissues by which they are bound together, is called, fascia.

4th. Kind of tissues, nervous tissues. This comprises two distinct structures, the fibrous and the ganglionic vesicular The first kind forms the essential constituent of nerves and the interior of the brain, the second kind, the different ganglia, the outer layer of the brain and the inner portion of the spinal column.

The vital parts of the human body are composed of these tissues which complexly arranged enter into the organization of the human system. Some of these organs are so essential to life that, with the cessation of their action, life becomes extinct. These vital organs are termed primary organs and regulate the other organs which are called secondary. None of these organs can act unless the heart sends into the brain a certain quantity of blood, vivified by its contact with the atmospheric air in the pulmonary tissue; hence the primary organs are usually spoken of as the heart, brain and lungs. The oxidation of the blood and its distribution into all the organs is, therefore, the chief phenomenon on which the life of man and of the most perfect beings depends. This constitutes the life of man from a Physiological standpoint. That concludes what we have to say about life from the standpoint of Physiology.

SYMPATHY AND HABIT.

All the different parts of the body are bound together by close relations and sustain these relations by means of sensations and affections—affections used here in its Physiological sense. Now these bonds which unite all the organs by establishing perfect harmony among all the actions taking place in the animal economy are called sympathies. The cause of these sympathies we cannot state. We do not know why when one part is irritated another part—although it may be far distant—partakes in the irritation. We cannot tell what are the means of establishing such sympathies, nor can we follow the connection of organ with organ when the affection is mutual. The only thing we know is that the mutual affection or sympathy exists. This sympathy, on account of this mysterious action and influence is all the more important in the animal economy, for such sympathetic relations form one of the most important differences between animals and the unorganized bodies, in which we find no sympathy at all, except so far as it exists in chemical affinity. Nothing in the inorganic world bears any resemblance to this sympathy, unless it be the magnetic or electric fluid. In the animal life, however, the connnctions are apparent and the effect visible, although the cause is secret. The nerves cannot be exclusive media of this sympathy for some muscles which receive branches from the same nerve do not sympathize, and some parts of the body are in close sympathy whose nerves have no connection. Each nervous branch having a connection in the brain and in the part to which it is sent, remaining distinct from those of the same trunk. There are different kinds of sympathy—that is physiologically. We will analyze some of these kinds of sympathy.

1st. Functional sympathy: on the part of two organs discharging the same function or functions. Ex., the kidneys may discharge each others duty. The uterus and the breasts during pregnancy are mutually sympathetic.

2d. Membranous sympathy, which is due to the continuity of the membrane, for example: stone in the bladder associated with an itching in

the glands—the membranes in that case being continuous. Fluid secretion is carried on in this way—that is by this membranous sympathy, as when food is in the mouth we find an irritation of the parotid ducts and glands, which tends to increase secretion. These are all exemples of the membranous sympathy.

3d. The irritation of the pituitary gland—which is found, as you know, in the sphenoid bone—results in the contraction of the diaphragm, and, as a physical result sneezing follows. Haller, the great physiologist, ascrided this to reaction. When snuff produces too great an impression on the olfactory nerves the uncomfortable sensation is sent to the brain, which, in turn, determines toward the diaphragm sufficient motion to contract the chest and so expel the air and the substance giving discomfort.

4th. The principle of life seems to nontrol the phenomena of sympathies. Ex., The rectum, when irritated by excrements contracts—the contraction taking place through sympathy. There is an accessory and a simultaneous action of the diaphragm anp the abdominal muscles.

5th. In the symmetrical organs possibly habit may explain sympathy—that is the reason we associated sympathy with habit—because, in this place it is explained by habit. Ex., When the sight is directed toward an object placed laterally the rectus externus of the eye of that side acts at the same time as the rectus internus of the other eye—that sympathy being explained by habit. These examples show us that sympathy exists, but,whether it is due to action, contractility, sensibility or to the vital force we cannot tell. It is by sympathy that all the organs concur to the same end and give each other mutual aid. It also explains how local affections spread and give effect to the whole system. Sympathy is thus both a physiological and pathological condition.

General diseases always originate by associations in the isolated affection of an organ or system. This, of course, is a pathological, rather than a physiological statement. The most complex affections—physiological affections—consist really of only one, or a very small number of elements, all the rest are accessories depending upon sympathy. This is an Osteopathic idea which traces the complexity of affections to a unitary cause in some function, organ or system.

The stomach, when irritated, gives rise to pains in the head and in the limbs, with burning heat and nausea, loss of appetite and anxiety affecting the whole system. The stomach thus oppressed spontaneously contracts to rid itself of itself of its nauseous contents and this produces an universal disturbance in the system, the affected organ calling to its aid all other organs. In this way by organic combinations in the form of pathological insurrections nature struggles to free itself from its morbid conditions. To assitt nature in this sympathetic action is to act the part of a physiological physician.

Habit consists in the frequent repitition of certain actions or motions, either by the whole body or by a part of it. The greatest effect of habit is to weaken the organic sensibility. For example: To use snuff, at first increases the mucous secretion of the nose, but, if it is used for a certain time, it ceases to have any effect on the pituitary membrane.

We become aware of our existence by means of sensations. All life congists in the action of stimuli on the vital powers. Sentient beings feel the necessity of continued emotions and, all the vital actions bear upon the the production of agreeable sensations.

Pleasure and pain; the extremes of sensation approximate to each other under the influence of habit, for habitual suffering renders us insensible to pain.

The organs of the body, some of them more than others, are influenced in their actions very powerfully by habit. By some physiologists this idea is carried so far that they regard death as a natural consequence of the law of sensibility. Life, according to this view, consists of the constant excitement of living solids by the fluids of the body, resulting because the sensitive parts after long habituation to this excitement cease to have the capacity of feeling.

We find a marked difference in the physiologica and psychological fields, in regard to habit. The physiological axiom is that habit impairs the sensitive power, whereas the psychological principle is that habit improves the judgement. Physiology says impairs and psychology says improves—so that habit reduces physical sensibility and improves intelligence, giving facility to all the actions under the control of the will. That finishes what we have to sap about habit. We pass on to the

VITAL FORCE.

These words do not represent a being independent of actions, but they represent the sum of those parts which animate living bodies in distinction from inert matter. From a remote antiquity the differences between organized and inorganized bodies have led to the hypothesis of a principle underlying all activity, a force harmonizing all the functions of life and directing them to the preservation of the individual life and species life. This ancient doctrine has passed down to us through the ages almost unchanged —that is the doctrine of a life-principle, subjecting animal life to laws differing from those of inanimate matter, a force that raises them above the mere chemical affinities and a free life-principle pervading the whole system, securing functional harmony and promoting unitary action on the part of the organs—this includes all the organs of the body. All the phenomena which we observe in the living human body are proofs of the existence of this life principle which animates the body and all the functions of the animal kingdom establish it. The multitude of the phenomena in the human life are reduced to a focus by harmonies, mutual connections and reciprocal independence. All the powers which animate the separate organs unite themselves and are combined together in this life-principle. This vital power is in constant conflict with the powers which govern inanimate bodies. The law of individual life is always struggling against universal nature. Life is this struggle determined in favor of the individual and death is this struggle determined against the individual; when the individual falls once more into the lifeless form. This vital force is constantly influencing, modifying and altering the physical laws. Although the principle of life is not seated in any one organ, or part of the living being but animates every organ, yet there are in the living body certain parts which are more alive than others and from which others derive their life and motion. These central foci of vitality gradually diminish in number in the animals as we get farther away from man, so that in the lower animals, life is more generally diffused and less centralized, until we reach in the downward scale complete diffusion of life, and loss of centralization. This course is not only traced down into the animal, but also into the vegetable life.

This vital force is not the soul, for this would bring us into the realm of metaphysics. We can illustrate this point by an example: If a nail is thrust into a sensitive part of the body a sharp pain is felt—that is normally—the fluids rushing to the injured part which becomes swollen and highly sensitive. All the vital powers in this process are quickly aroused and sensibility becomes more acute; contractility is intensified and there is a rise of temperature.

This does not mean that the soul is awakened, but that the vital powers of the body are aroused, sensibility and irritability. In this way the vital principle which watches over the vital properties and protects its functions comes to the rescue of the injured organ and manifests its existence, first by arousing and then directing the action of the vital powers. Martyn Paine has shown that there is only one vital principle—this in opposition to a great number of writers who preceded him who tried to show that there were a number of vital principles. Organized matter possesses certain inherent properties which manifest the phenomena of life. There are two of these inherent properties: 1st. Susceptibility, or the capacity of receiving impressions, and, 2d., vital affinity which produces atomic changes resulting from received impressions. These constitute the elementary properties of organized and living matter, whether in protoplasm or bioplasm in virtue of which there is a capacity of development. These are the two properties of the vital force.

The human body may be subjected to minute examination after dissection under the microscope. From this examination the matter of the body is found to consist of certain structural substances, which by chemical examination are found to possess certain characteristics, the chief of which is that of potential energy, which can be set free by oxidation or other chemical processes.

The body consists, therefore, of several chemical substances which, on the whole, contain a large amount of potential energy. This is true of the living body; at death the body contains still a large capital stock of energy, but this capital is soon exhausted under the processes which accompany putrefaction. The body, once living, is soon reduced to dust and the stock which was once stored in the body is soon exhausted because there is no repair or replacement.

In the living body we notice certain characteristics. There are six in number and we will name them one by one.

1st. Activity, represented in movements, either of the body upon itself, or of the entire body from place to place, locomotive movement. This activity is essentially internal and represents the energy of the body itself.

2d. External circumstances often determine this activity. Ex.: Bodily sensibility and contact form the two bases of such movements.

3d. There is a continual process of heat generation, and heat giving forth, going on in the body, by which animal heat is produced and preserved in the body, thus giving to the body a normal temperature above its environment and which it imparts to other bodies.

4th. The body is sustained by taking in the food substance similar to the body substance assimilating it to the animal nature and using it as nutriment to supply the body with free energy.

5th. By respiration, the body continually supplies itself with fresh oxygen.

6th. The body gives out, from time to time, waste matter, the result of oxidation of the food substance, or of a part of the body substance. The living body, therefore, is to be distinguished from the dead body in three particulars.

1st. It is constantly losing energy, and as constantly replenishing its stock of energy.

2nd. In the dead body, all the liberated energy passes off in the form of heat: while in the living body, it is set free from the body in mechanical movements, and even while existing in the body, it assumes forms that are different from heat, although, finally changed into heat in some form.

3rd. In the dead body external bodies affect it only in setting free quantities of heat which result in decomposition, while in the living body the liberated energy assumes some form of motion from the most simple movements of the body, or a part of the body, to the most violent and sudden contortions of the bodily system.

The main problem of physiology, therefore, is to explain how the living body can do what the dead body cannot do, namely:

1st. Restore its lost energy through the renewal of its substance and,

2nd., give out from itself, not only a certain amount of free energy but a certain kind of energy determinate and special. The human body from its earliest stages is divided into parts which are different from each other and become more different—the differentiation increases as growth advances. The cells of the body are differentiated in such a way that groups of cells unite together to form certain tissues, the whole body ultimately consisting of masses of such tissues, each tissue having its own structure. Each tissue differs, not only in structure from every other tissue, but ultimately each tissue assumes particular functions, there being an accurate division of labor among these tissues. Aside from this histological structure of tissue, physiology takes account of two divisions of tissue. You remember histology gives us four divisions, physiology reduces these to two.

The Physiological division is based upon function or use.

1st. Those which are employed in restoring lost energy by renewing the substance.

2d. Those which are used in freeing energy to be converted into heat and motion. In the main, nervous tissue is used in the production and distribution of nervous impulses and the muscular tissue in the production and direction of movements, these movements being directed controlled and harmonized with the environments by nervous tissue. In any case, energy is expended, and this energy being converted into heat leaves the body either in the form of heat or mechanical work. This necessitates the replenishing of energy and the renewal of the substance. In order to assist these two main tissues in the processes of renewal and throwing off waste, all the organs of the body are brought into service to animalize the food substance, and so prepare it for use by muscular and nervous tissues, and also, to take up and finally eject from the body its waste. From this standpoint we have two other kinds of tissues, physiologically.

1st. Tissues of alimentation which take up and prepare the food, and 2d, tissues of excretion which clear away the waste materials in order that muscular and nervous tissues may have the least trouble in the process of up-building. These tissues are arranged in organs, and these organs represent mechanisms, whose movements are carried on by muscular tissue under the direction of nervous tissue. Thus we have two classes of muscular tissues, the one concerned with external locomotion, and the other with internal organic movements. There are, also, two classes of nervous tissues, the one bearing upon the external movements, and the other upon internal movements. When the food substance is prepared for nutriment, it is carried to the different tissues by means of blood, which, under the

control of the vascular system circulates all through the body carrying nutriment to the various tissues, and also, by the respiratory system, bearing the oxygen supply to its tissues according to their needs—that is the needs of these tissues—in the economy of nature. This, in outline, gives us a brief sketch of Physiology as a science, and of the physiological functions, of the light thrown upon the subject by chemistry, biology, anatomy and pathology, of the vital principle which permeates the entire physiological subject and of the complete harmony among the different organs whose functions, though distinct, are part of that unital arrangement by which the human body fulfills its purpose in the preservation and manifestation of the individual life and in the transmission of that life from generation to generation in the life and history of the species.

CHAPTER II. THE BLOOD.

SECTION I. The General Physical and Physiological Properties.

The different tissues of the body are interlaced with a network of fine vessels, the capillaries, to which the blood is carried by the arteries, and from which it is conveyed by the veins. The blood is contained practically within this tubular system and is kept in circulation mainly by the force of the heart's action. This blood is in reality a tissue of the body, and in its circulation is really concerned with the whole field of physiological life and development, carrying the animalized materials to the different tissues; carrying the oxygen absorbed by the lungs also into the tissues; carrying off its waste products, and assisting in the regulation of the animal temperature. Here we are to consider not this physiological action, but the blood as a constituent element of the body. That is, we consider the constitution of the blood rather than its functions. These functions belong to the different fields of physiology that follow in connection with the different organs of the body.

The blood in its liquid form consists of the plasma, also called the liquor sanguinis, an almost colorless fluid in which flow, at least, four different kinds of corpuscles.

The corpuscles are minute bodies, some regular and some irregular, and are known as the red corpuscles, the white corpuscles or leucocytes, the blood plates, plaques or platelets, and 4th, the granules. The blood plasma is colorless when it is free from the corpuscles, or of a faint straw color when it is seen in large quantities. This straw color being due to the presence in the plasma of pigment of a special kind.

The proportion of plasma to corpuscles in size is usually stated about 2 to 1. The blood plasma is the liquid part of the blood before coagulation and differs from the blood serum, which is the liquid part of the blood squeezed out of the blood when it coagulates. The reaction of the blood is alkaline, due to the presence of the alkaline salts in the blood, chiefly the carbonates of soda. In different animals we find this alkalinity varying. Reckoning it as carbonate of sodium, (Na_2CO_3), human blood corresponds to .35 per cent of this salt. This is very important, because during the process of digestion the alkaline reaction is said to be increased while exercise causes a diminution. The specific gravity in the adult male may vary from 1,045 to 1,075, the average being 1,055, whereas, in the female the variation is from 1,041 to 1,070, the average being 1,050. It also varies with age. It is increased by exercise and rises normally during the night, being, decreased after meals, during the day and after hemorrhage. The specific gravity of the corpuscles is greater than that of the plasma, hence the corpuscles when coagulation is prevented, tend to sink—that is, to sink in the plasma. This specific gravity varies among these corpuscles themselves—the red corpuscles being heaviest and the plaques being lightest. The redness of the blood is due to these corpuscles. The plasma in the living vessels appears to be colorless as does the serum in thin layers—in thick layers the plasma and serum have a slight yellow color due to the presence of pigment. These red corpuscles in man, and in the mammals, except the camels who are of the camelidæ family, are bi-concave discs without nuclei with a diameter of from 7 to 8 micra, (one micron equalling .001 mm) and a thickness of one to two micra. Being discs they are circular when viewed on the flat and rod shaped when viewed on the profile. In number they vary much in health and during sickness, the average being five millions per cubic millimeter in the male and four million five hundred thousand in the female—this number is affected by increase or deerease of the plasma, or by increase or decrease of the the red corpuscles. The number varies with the constitution, nutrition and manner of life, and also with age; they are greatest in the fœtus and new born child. It varies also with altitude—a high altitude increasing the number of corpuscles; a diminished pressure of oxygen in the air increases the production of these corpuscles. The increase or decrease in the number of corpuscles takes place in normal conditions according to the changes in the tissues and by the presence or absence of water in the blood, and also by abnormal conditions relating to the number and size of the corpuscles—these abnormal conditions belong to pathology, not to physiology. The red color of the corpuscles is due to the presence of hæmoglobin, and this may also determine the condition of the blood, whether normal or abnormal. When seen microscopically these corpuscles, taken singly, have a faint red color, yellowized; but when they are seen in masses they are blood red, varying from the scarlet red of arterial blood to the purple red of venous, this variation being due to the amount of oxygen in combination with hæmoglobin. The red corpuscle is elastic as it may be deflected under pressure, resuming its original form after the removal of the pressure. The shape of the red corpuscles, therefore, depends upon physical conditions of the plasma, serum, or the fluid in which they are found for the time. These corpuscles consist of a colorless framework (not compact), which is spoken of as the stroma. This stroma is a differentiated protoplasm consisting of proteid substance and other matter. This stroma is normally associated with hæmoglobin, which may be analyzed into proteid matter of the globulin family, and the coloring pigment of hæmatin. In general the function of the red corpuscles is to carry oxygen from the lungs to the various tissues. This function depends upon the presence of hæmoglobin, which easily combines with oxygen gas. Of the total solid matter of the corpuscle about 95 per cent is hæmoglobin. The combination of the hæmoglobin and stroma is not known, physiologically. In laky blood the corpuscles are broken up and the hæmoglobin is set free passing into the plasma in solution, the redness being diffused in the serum. Normal blood is opaque, due to the reflection of light from the surface of several corpuscles. Laky blood, on the other hand, is transparent because there is no longer the surfaces of the corpuscles to reflect the light. The blood may be made laky either by ether, chloroform or bile, and this is the abnormal condition that we find sometimes in the living bodies as well as by the addition of a large excess of water. Landois, by several experiments, has shown that the serum of one animal's blood may render laky blood of another animal—a condition that is of some importance in the subject of transfusion, an abnormal condition of the blood. This property is called globulicidality, different kinds of serum possessing this property in different degrees. If the blood is diluted with water, the blood becames laky after a certain point is reached. The quantity of water required differing in different animals. In the red corpuscles a certain amount of water is present normally; the amount being determined by the substance—the substance of the corpuscles—and the attraction of surrounding liquids. If this attraction is diminished or destroyed, water passes freely into the corpuscles, and forces out the hæmoglobin. Liquids containing inorganic salts sufficient in quantities to prevent the corpuscles imbibing water are spoken of as isotonics to the corpuscles—that is these salts prevent the corpuscles dissolving and giving up their hæmoglobin. Ex., Sodium Chloride 0.65 per cent solution acts as such an isotonic. There are a number of other isotonics, but this is the one that works the most perfect.

Hæmoglobin is a very complex substance of the compound proteid class. When analyzed it is found to consist of 96 per cent of proteid (globulin) and 4 per cent of pigment (hæmatin). In the absence of oxygen decomposition produces globulin and hæmachromagen (this last is a compound substance), when oxygen is present under oxidation giving place to hæmatin. This compound substance combines readily with oxygen and gives it its absorbent power, giving to the hæmoglobin its physiological property, which is utilized in respiration—that is carrying the air from the lungs to the tissues. Hæmoglobin seems to be different in different animals, theamount varying with the individual and with the condition of life.

In the blood of a man weighing 68 kilograms—that is 150 pounds—there are found about 750 grams—1.65 lbs.— of hæmoglobin distributed among 25 trillions of corpuscles. This vast extent of the hæmoglobin is used for absorbing oxygen in the lungs, the bi-concave form of the corpuscles increasing the surface, which is open to the air's action. Hæmoglobin unites freely with air, forming a chemical compound known as oxy-hæmoglobin. This combination, the oxy-hæmoglobin, is not very stable, so that if the compound is placed where oxygen does not exist it gives off its load of oxygen, a property of the blood which is of great use in respiration. The hæmoglobin unites with carbon monoxide (CO), to form a very stable compound, for this reason, the inhaling of the carbon monoxide gas results generally in death by asphyxia. This carbon monoxide gas, of course, is found in the coal gas. That is one reason why coal gas is so fatal. The same is true of nitric oxide (NO).

Iron is found to be present in the hæmoglobin, varying in different animals; the per cent being from .34 to .48. This iron element is of great value in combining with oxygen. Each atom of iron in the hæmoglobin molecule combining with it one molecule of oxygen. Oxy-hæmoglobin may be found in crystal form, the power of crystallization varying in the blood of different animals. If we take some blood and put it into a test tube, then add a few drops of ether, shake the blood until it becomes laky—you know we said ether and chloroform were substances which produce that condition, shake the blood until it becomes laky, and then put the tube on ice until the crystals deposit. Small portions of this crystal may be examined under the microscope. These crystals assume different forms in different animals. In man and most of the animals they assume the rhombic prism form. Hæmoglobin in solution, examined under the spectroscope, gives characteristic absorption bands.

THE RED CORPUSCLE is a cell that has lost its nucleus. The corpuscles therefore, do not live long in circulation—that is in their individual form. The bile pigment discharged from the liver is derived from hæmatin, which is a decomposed product of hæmoglobin. As these pigments are continually excreted the red corpuscles, which supply the hæmoglobin must be constantly destroyed in a normal state of health. It was formerly believed that the spleen, where red corpuscles have been found in various stages of decomposition, that the destruction of these corpuscles takes place in the spleen. Later researches, however, have shown that the blood of the splenic vein contains no hæmoglobin in solution. It is more probable that no special organ or tissue destroys these red corpuscles—that is, it has no special function—but that the process of dissolution goes on in any part of the circulation, the hæmoglobin thus set free going to the liver and being excreted as bile pigment. This constant destruction of red corpuscles demands a constant formation of new ones. In adult life the red marrow of the bones is the great reproducer of the red corpuscles. In the passages of the capillaries and minute veins of the marrow are found nucleated colorless cells, these being transformed into non-nucleated cells, and then passing into the blood as red corpuscles. In the embryonic life this process goes on in other parts of the body, such as the spleen and the liver, as well as in the red marrow of the bones.

THE WHITE CORPUSCLES OR LEUCOCYTES. These are less numerous than the red corpuscles, the variation ranging from one in three hundred to one in seven hundred. Although they are less in number, they seem to be of greater importance in their relation to the blood. At rest they are colorless, irregular, spherical masses, varying in size with an average diameter of ten micra and of a coarse granular form. They often change their form and thus possess amœboid movements. In these movements the spherical form of the corpuscles may be changed to the flat plate form in which it displays a nucleus and sometimes two or more nuclei. These leucocytes are examples of undifferentiated protoplasm. The whole corpuscle contains a large proportion of its substance, water, only ten per cent being solid. This small solid proportion consists chiefly of proteids, for example myosin, similar to, if not the same as muscle myosin, paraglobulin, nuclein, containing a large quantity of phosphorous. In addition to the proteids we find fatty matter, starch and sugar—not in their clear form—together with quantities of potassium and phosphorus. The blood leucocytes are of different kinds, the chief characteristic being the amœboid movements, by which they readily pass about absorbing into their substance fatty or pigmentary substance, wandering about from place to place, and even passing through the vessel walls as in diapedesis. This process takes place to a slight extent normally, but is largely increased by inflammation. Sometimes they are called migratory or wandering cells. Various classifications have been given of these corpuscles. In recent times they are usually spoken of as three in number.

1st. The lymphocytes: small corpuscles with a round vesicular nucleus, incapable of amœboid movements. These resemble the leucocytes. They are found in the lymphatic glands, and, in fact they pass into the blood from the lymphatics, supplying the blood with new white corpuscles.

2nd. Mononuclear leucocytes. These are medium sized corpuscles with a vesicular nucleus, and possessing amœboid movements.

3rd. Poly-nucleated leucocytes. These are large corpuscles with a tripartite nucleus, and they show active amœboid movements. According to some physiologists these different classes of corpuscles represent progressive stages of the corpuscular development. The difference in form depending upon the stage of development. Other physiologists regard the corpuscles as all belonging to one family, the difference being due to the taking in of granules or the production within the cell itself of certain granules as products of metabolism. The functions of these corpuscles are numerous. We may classify them under four heads.

1st. They aid in absorption, for example, the absorption of fats and proteids from the intestine. In this case the absorption takes place in the lymphatic tissue of the alimentary canal by the lymphocytes.

2nd. They aid in the process of coagulation.

3d. They help to maintain in normal condition all the blood plasma by supplying it with proteid matter.

4th. They are said to protect the blood from the pathogenic bacteria. It is claimed that these leucocytes either eat up the foreign substance introduced into the blood, hence they are called sometimes phagocytes, or else they form certain substances which destroy these foreign substances. This is the basis of the theory of immunity from infectious disease effected by inoculation, e. g. vaccination.

THE BLOOD PLATES OR PLAQUES.—These are small disc shaped or irregularly rounded bodies, ranging in size from .5 to 5 micra in diameter, but homogeneous in their structure. According to Hayem they were early stages of the developing red corpuscles and he calls them hæmatoblasts; this, however, from later research is erroneous. On removal from circulating blood they rapidly dissolve, and this dissolution for a length of time prevented their microscopic examination. They exist in the blood itself and are not products of coagulation. Lilienfield has shown that they consist of a nucleo-albumin which is found, also, in the nuclei of leucocytes. When these poly-nucleated leucocytes dissolve in the blood, these nuclear fragments exist for a time as plates or plaques. If this statement is true the function of these plates is either to build up the plasma or they form a waste which is thrown off through the plasma from the body, in addition to aiding in the process of coagulation. Gibson calls them colorless microcytes.

The 4th kind of corpuscles; elementary granules: These consist of fatty substance derived from the chyle and small protoplasmic germs produced by the lymphatic glands. They constitute the smallest and undifferentiated elements that are found in the blood.

SECTION 2. Chemical Composition of the Blood.

The blood, including the plasma and the corpuscles, contains a great number of substances, the chief chemical interests of the blood being found in the changes which it undergoes in the several tissues, and as a source of food supply, and also, in carrying off the waste products. The whole blood contains gases in certain proportions, chiefly the three gases; oxygen, carbon dioxide, nitrogen. These gases vary in the different kinds of blood, and especially distinguish arterial blood from venous blood. In a quantity of blood containing a hundred volumes, we find the following proportions in the two kinds of blood:

Arterial blood	O, 20.	CO_2, 40	N, 1 to 2.
Venous blood	O, 8 to 12.	CO_2, 46	N, 1 to 2.

The plasma is resolved by coagulation into serum and fibrin. If the corpuscles retain the proper quantity of water necessary to their integrity, then the blood consists of from 1-3 to 1-2 by weight of corpuscles, the rest plasma. The constituents of blood, chemically analyzed, are found to be as follows: Water; proteids, three kinds of which exist in the plasma; fibrinogen, paraglobulin and serum albumin; combined proteids, hæmoglobin and nucleo-albumin; fats and other extractives, such as sugar, urea, uric acid, etc.; and lastly inorganic salts. The plasma consists of the three proteids fibrinogen, parag lobulin and serum albumin. In one hundred parts of serum we find about 90 parts of water, 1 to 2 parts of fatty substance and other extractives and 8 or 9 parts of the proteids. Fibrinogen: This belongs to the globulin family and is distinguished from paraglobulin by a number of special reactions. Its chief reaction is that under proper conditions it gives rise to an insoluble proteid fibrin which is essential in the blood coagulation. It occurs in small quantities in the blood, varying from .2 per cent. to .4 per cent. Its function in the blood, aside from coagulation, is unknown. Paraglobulin: This, also belongs to the globulin family, exhibiting the general reaction of this class. The amount of it found in different animals varies. In man it is about three per cent. This proteid is valuable as a source of nitrogenous food to the different tissues, but, whether it is used directly by the tissues or by conversion into another proteid is uncertain. Serum albumin: This is a typical proteid showing the general reaction of albumin. In the blood it comprises all the proteids that are not precipitated by the sulphate of magnesium ($Mg\ SO_4$). It is said that heating under proper conditions gives coagulation at three different temperatures, indicating the presence of the three proteids mentioned. The amount varies in different animals; in man being about 4.5 per cent. It is generally believed to arise from the digested products of the food, not being changed during the process of digestion, but during the act of absorption into the blood.

Physiologically this serum albumin is the chief source of proteid nourishment for the tissues of the body, furnishing part of the proteid material made use of in the metabolism of the tissues. The fatty substances, which are scarce, except after meals or under pathological conditions consist of the neutral fats, for example: Stearin, palmatin and olein with a certain quantity of their respective alkalines. Among the extractives we find nearly all the extractives of the body and the food, for example: Sugar urea, kreatin, etc. The chief chemical feature of the saline constitution of the blood—that is the blood plasma—is the predominance of sodium over potassium salts, the abundance of chlorides and the presence of phosphates or their presence in very small quantities. The red blood corpuscles contain about 60 per cent. of water and 40 per cent. of solids.; 39 per cent. of the 40 per cent. being organic, chiefly hæmoglobin, to the extent of 30 per cent., that is the hæmaglobin. We find about 1 per cent. of lecithin and cholesterin. The salts consist chiefly of potassium and .5 of magnesium, calcium and only very small traces of chloride of sodium. The chief acid is phosphoric acid, about .2 per cent. combined with potassium to form the phosphates. In the white corpuscles the chief proteids consist of myosin and paraglobulin. In the nuclei we find nuclein. We also find lecithin and other fats, glycogen, the extractives and the inorganic salts, the potassium salts predominating.

SECTION III. Coagulation of the Blood.

The blood when shed from the living body is perfectly liquid. Soon, however, it becomes coagulated, and this viscidity is one of the most important properties of the blood, after it escapes from the body. The process of coagulation is easily followed. The blood when shed from the vessels very soon becomes viscous and then settles into a jelly or gelatinous condition, quickly becomes more firm, thus preserving the mould of the vessel. If the blood is left in this jelly condition however it becomes more compact; it shrinks and yields a quantity of faintly yellow colored fluid which is called the blood serum. This liquid appears first in layers on the top, then around the sides, and last on the bottom surfaces of the compact substance—the gelatinous substance. This jelly substance after shrinking assumes a more solid consistency, forming a clot, or, as it is sometimes called in its Latin form, crassamentum. In the process of clotting the upper surface becomes slightly concave; the clot itself assuming the form of a network of fine fibrils, in the midst of which are found entangled the red and white corpuscles. These fibrils are found to be composed of fibrin, an insoluble proteid not present in the normal blood. This fibrin appears in the fine threads which hold the clot in its gelatinous condition; the corpuscles being held firmly in the filaments of this fibrin. The white corpuscles on account of their capacity for amoeboid movements often pass out into the serum. If the blood is shaken after being drawn the filaments are broken and the serum becomes red instead of pale yellow, due to the presence of the red corpuscles.

If the blood is vigorously whipped with a bundle of rods the fibrin will be deposited on the rods and the liquid then left will consist of serum and blood corpuscles. This whipped blood is called defibrinated blood, resembling ordinary blood with this exception, that it cannot clot again. The Physiological value of coagulation is that it causes haemorrhage to cease by binding up the wounded vessel. The time taken for clotting varies; but, normally in human blood it becomes viscous, that is the first stage, in from two to three minutes, assuming the jelly form, the second stage, in from six to ten minutes. In a few minutes more the first serum drops, representing the third stage, appear, and this goes on gradually, being usually completed in from ten to forty-eight hours.

In the blood of the horse the process of coagulation is slow, allowing the red corpuscles and some of the white to sink to the bottom before viscidity begins so that the upper part of the clot assumes a lighter color, while the lower part of the clot is a dark red color. The upper part of this clot is called the buffy coat, and the clot is said to be buffed. The blood of the pigeon clots almost as soon as it is shed, some say even in the process of shedding; whereas the blood of the chicken may not coagulate for ten or twelve days, retaining its liquid form for that length of time. The clotting may be accelerated by the following circumstances:

1st. By the presence of Oxygen, viz., the free access or the air.

2d. In a temperature a little above that of the blood, for example, hot sponges or fomentations applied to a wound accelerate clotting.

3d. Contact with foreign bodies, or the increase of the extent of the substance with which the blood comes into contact, for example, the extent of the vessel in which the blood is placed. Blood will also coagulate in a vacuum, but this may be prevented by taking precautions to prevent agitation of the blood and by keeping the temperature of the vessel nearly that of the blood vessel from which the blood has been taken. Coagulation is retarded and may even be prevented altogether:

1st. By the absence of Oxygen. This may seem to conflict with the statement we made before in connection with the vacuum. But in the vacuum we have a peculiar condition depending upon pressere and also the presence or absence of certain gases in the blood which is not a normal condition of the blood as we find it in the vacuum, and this is the reason why in the vacuum we have the tendency to accelerate rather than retard coagulation.

2nd. By a temperature below zero or above 60 degrees centigrade. For example, blood from animals which normally clots slowly may be put into narrow vessels surrounded with ice. In this case coagulation is retarded, the process of coagulation is retarded, and may be even prevented. Blood in this way may be kept for an indefinite time in a fluid condition. The corpuscles sink—that is in this condition when the blood is put in a narrow vessel surrounded by ice—and in this way we get the pure blood plasma.

3d. By the addition of neutral salts, for example, Sulphate of soda, Magnesium sulphate, carbonates of sodium and potassium, the nitrate of potassium, and the alkaline chlorides. In this case the corpuscles settle and we get plasma that is known as salted plasma due to the presence of these neutral salts. The best solution to use when securing this salted plasma is a solution of 27 per cent magnesium sulphate.

4th. By saturation of the blood with carbon dioxide (CO_2).

5th. By certain albumose solutions. Some of the products of proteid digestion, for example, peptones and albumoses. These injected into the blood in the living vessel retard coagulation for a long time—we speak of the living vessel for even in a case of death of the body, the vessel lives after the death of the body for a certain time—that is why we mention the living vessel after death—the death of the body or after its removal from the body.

6th. By the use of an extract from the heads of leeches.

Normally coagulation does not take place while the blood is in circulation through the vessels. It would seem that the living walls of the vessels, the lining membrane of the walls of the vessels prevents this clotting. Many of the conditions that we find in the living body are favorable to coagulation, but in addition to these conditions the blood continues to sustain an intimate relation to the living tissue. For example, if the base of a frog's heart be ligatured while pulsating, the blood remains fluid in the beating heart—that is, the heart of the frog continues for two or three days in this condition—so that the process of ligature is quite easy. But if the heart be punctured, the drop that oozes out from the puncture coagulates almost instantaneously. Lister maintains that coagulation is produced by contact with foreign bodies, and he says that this is the only cause of coagulation. In the case that we mentioned, that is the case of the frog's heart, he says that the blood was kept agitated by the heart's beat. But the blood will continue fluid in an artery between two ligatures for a considerable time, and that, of course, is independent of the beat. Blood coagulates more slowly in a dead vessel—that is a dead vessel that once was alive in the living body—than when shed and placed in an artificial vessel. Coagulation first commences in the heart and the iarger vessels, then passes to the intermediate vessels, and last of all to the smallest vessels. In the case of the smallest vessels, decomposition sometimes sets in before coagulation takes place. The cause of coagulation and the theories of explaining it are as yet shrouded in mystery. Two things are to be explained in connection with coagulation.

1st. The formation of fibrin, and second, the question of the derivation of fibrin from the fibrinogen of the plasma. Hewson in 1772 was the first

to state that fibrin was disolved in the blood, and that it coagulated to form a clot. Prof. Buchanan, at one time Prof. of the University of Glasgow in Scotland in 1845 showed that two substances are necessary in order to form fibrin, by proving that certain fluids, for example, Hydrocele fluid, which do not coagulate spontaneously undergo this change, when part of a clot, or fluid from the clot are added to it. He concluded from this that there is a soluble fibrin which, when acted upon by the colorless blood corpuscles —the white corpuscles—produces fibrin.

Schmidt, who has investigated the subject for over thirty years, has given us the most recent theory of coagulation.

At first he discovered fibrinogen (this was away back in the '60s, about 61 or 62,) which he found in the blood plasma and in the lymph, belonging to the globulin family of albuminous bodies, fibrin being formed by a union of fibrinogen with fibrinoplastin or paraglobulin—this last, also, is of the globulin family derived from the blood serum.

Schmidt's latest theory—which we find in connection with his researches of about three years ago, 1894, in regard to coagulation, is that three conditions are necessary to produce coagulation. 1st, certain proteids, the two globulins of the blood. Out of the paraglobulin is formed the fibrinogen, and this fibrinogen is changed into fibrin.

2d. The fibrin ferment is necessary in order to effect these changes. This ferment Schmidt calls thrombin.

3d. A certain quantity of neutral salts is necessary in order to precipitate fibrin in its insoluble form—that is as we find it in the clot. This ferment he formed by adding to the serum of ox blood twenty times its volume of strong alcohol, setting it aside for a month. After the close of the month the coagulated proteids were extracted by means of distilled water, and in this way there was obtained a solution containing small quantities of proteid—a solution which he found to assist, and also to induce coagulation. He did not go so far as to use the word produce, but to induce, to assist and induce coagulation. Schmidt held that this ferment was formed in shed blood by the disintegration of the leucocytes or white corpuscles. At the present time it is believed that there is derived from this disintegration of the leucocytes and also from the disintegration of the microcytes—these are the blood plates called microcytes—a ferment necessary to coagulation. So far as our knowledge extends at the present time, we conclude that the formation of fibrin is due to the action of this fibrin ferment upon fibrinogen and that both of these—both the fibrin and the fibrinogen—originate from the colorless corpuscles—the leucocytes and the microcytes. The blood does not clot within the vessels, normally, except in the case of intra-vascular clotting by the introduction of some foreign substance, which either injures the inner lining of the vessels, or acts as a ferment on the blood. The reason of its not clotting in the vessel is that the nucleo-proteids are not present in the blood in sufficient quantities at any one time to produce coagulation.

In the formation of the fibrin the leucocytes and the microcytes disintegrate in the blood in circulation, but this does not take place to a sufficient extent to form a ferment on account of the defensive activity of the cells lining the interior of the vessels. When this defensive cause is removed in shed blood, these nucleo-proteids combine with salts to form fibrinogen and fibrin with the result of the coagulation of the blood. This point may be accepted as settled in Physiology, viz.: that coagulation is due to the formation of fibrin—the mysterious point, of course, is in connection with the form of that fibrin—how the formation takes place. We also know that this does not take place in the blood normally, but that it is formed by the union of fibrinogen and paraglobulin, probably under the influence of the fibrin ferment. Fibrinogen exists in the blood plasma and paraglobulin also exists in the blood, principally in the corpuscles—some Physiologists say in the white corpuscles and some say in the red corpuscles. Some Physiologists say that the reason why the blood does not coagulate in the living vessel is that the fibrin and the paraglobulin are both contained in the white corpuscles; that the fibrin ferment is also derived from the white corpuscles, and as long as these white corpuscles remain intact, none of these substances, the fibrinogen, paraglobulin or fibrin, can escape so as to form by union the fibrin. If this disintegration of these white corpuscles takes place, these three substances escape and the result is the fibrin is formed, and, of course, coagulation results. This disintegration of the white corpuscles takes place when the blood is shed from the living vessels, and also when the epithelial lining of the vessel is injured or destroyed. In the former case we have blood coagulation, in the latter case we have intravascular clotting or thrombosis—a condition that is associated with the term that was used by Schmidt to represent the ferment, thrombin. The blood may be regarded as a tissue—like the other tissues of the body—made up of living elements requiring constant assimilation and elimination in order to maintain the normal life conditions. Coagulation, on the other hand, is the result of certain chemical changes concomitant with the death of the blood—that is we do not say the death of the body, or the individual, but the death of the blood, because these are distinct; while it lives—that is while the blood lives—no such changes take place. Constant chemical interchange between the blood and the walls of the vessels—the blood vessels—is required to sustain blood life, also the body life. It is the blood life that we discuss now. The solid formation found in the clot and the separation of a liquid proteid found in the serum is in line with what we find in other tissues of the body, for example, soft, contractile tissue at its death undergoes a change almost identical with coagulation; a condition that we have to deal with when we come to the Physiology of the muscles. The only thing that we know definitely in blood nutrition is this fact that a constant relation is required between the blood and the lining membrane of the vessel wall. Coagulation does not take place when this relation is preserved; but, in the case of a lesion of the delicate membrane—whether the lesion is due to injury or to malnutrition, coagulation follows. During the first stages of inflammation, on account of the arrest of the flow of blood, the small vessels suffer from defective nutrition, allowing certain of the blood elements to escape, while the corpuscles adhere together and the plasma coagulates. We find the same thing in the larger vessels, when an inflammation of the lining membrane of these larger vessels destroys the capacity of keeping up the delicate relation of the blood and the vessel walls. On the valves of the left side of the heart and in the arteries where the delicate relation of blood to the vessel wall is subjected to great strain we often find slight lesions covered with small blood clots. Foreign substances, for example, a thread introduced into the living and circulating human blood, form a clot, the colorless corpuscles collecting on the thread. The time necessary to produce intravascular clotting is long—that is compared with the extravascular, the blood having been stopped for several hours, some Physiologists say for even more than a day, without this coagulation. This is due to the fact that so long as the relation of the blood and vessel walls

is maintained, clotting does not take place. In fact, the tissues die before the blood will clot in the vessels; that is, you have the death of the tissue before you have the death of the blood. Even after death the tissues live and the blood continues fluid as long as the vessel wall can nourish itself and the blood. In cold-blooded animals the tissue lives longer than in the warm-blooded animals; for example, the heart of a tortoise will live under favorable conditions for two or three days after its removal from the body and the blood will still continue in its fluid condition until after the death of the heart, that is, after the death of the heart tissue. Certain chemical changes must go on in the blood to preserve this integrity—the integrity of the blood, the cessation of these changes resulting in new products among which you will find fibrin. When the blood is removed from the vessel wall, or the relation is broken, the production of fibrin results—from one of two causes—either:

1st. Because the blood elements have been destroyed, or

2nd. Because of the impossibility of the reintegration of those blood elements. In either of these cases the fibrin appears as a death element, in the case of intravascular clotting this death element is removed by the vigorous action of the other life elements in the body and in the tissues, while in the case of shed blood these life elements cease to exert an influence and hence complete coagulation results. This finishes the subject of coagulation of the blood.

SECTION 4. Quantity of Blood.

The total quantity of blood in the vascular system gained by balancing the blood supplied by the tissues which give to, and those which take away from the blood is estimated approximately by various physiologists.

The method used by Welcker is called the colorimetric method, which consists in bleeding the animal as thoroughly as possible and weighing the blood thus obtained, afterwards washing out the blood vessels very minutely with distilled water and estimating the amount of hæmoglobin in the blood washings. The result is that, in man 7.7 per cent. of the body weight is found to be blood, or about 1-13 of the body weight; for example, In the case of a man weighing 68 kilograms we find about 5,236 grams of blood in the body—that would bring it to just about 1-13 of the body weight. In the new born child the blood is found to constitute 5.25 per cent. of the body weight—that is 1-19 of the body weight, compared with 1-13 in the adult.

In the rabbit and in the cat—which are so favorable in physiological experiments—the blood has been found to weight 5 per cent. of the body weight—that is 1-20 of the body weight. In the same individual the variation is not very large at any moment, because a sudden drain upon the water of the blood, for example, by profuse perspiration is counteracted by the passage of water from the tissues to the blood, and vice versa—the reverse condition.

Torchanoff, the Russian physiologist, has invented another plan. He subjects the person to a Russian bath in which profuse perspiration takes place. The amount of hæmoglobin in the blood is determined both before and after the bath, and from this he estimates the total volume of blood—in that way you can find the correct amount of blood in the living being without subjecting them to the extortion of blood. The blood is distributed throughout the system as follows: Taking four parts as the basis; one part is found in the heart, the lungs, the large arteries and veins; one part is found in the liver; one part in the resting or skeletal muscles and one part in the other organs.

SECTION 5. Abnormal Conditions of the Blood.

This subject is sometimes excluded from physiology by physiologists because they say it belongs to pathology, but it is like some other subjects; the subject is excluded from physiology because it belongs to pathology and it is excluded from pathology because it belongs to physiology, and so it falls down between the two. So the best way is to take it up now. Several abnormal conditions of the blood have physiological bearings; for example, in plethora, or polyæmia there is an increase in the entire mass of the blood, uniformly in all the organs. There are several signs of this polyæmic condition; for example, the bluish-red skin, swollen veins, dilated arteries and the hard and full pulse. When accompanied with the brain congestion we find vertigo and congestion of the lungs. This polyæmic condition may be produced artificially by transfusion—that is by the injection of blood of the same species into the living vessels. If the quantity of blood be increased from 80 to 90 per cent. there is no danger to life, because this amount of blood can be accommodated in the distended vessels. But, if the quantity of blood injected reach 150 per cent life is imperiled. The cause of death would be in this case the sudden rupture of some of the vessels which distended to such an extent that it would result in rupture. Transfusion seems to affect the increase of red corpuscles, this being the most noticeable effect for the longest period—that is, there are other effects, but they are slight, as compared with this. Transfusion is a dangerous process; because the new blood introduced is likely to contain fibrin—at least in its germs, and this may result in intravascular clotting. In addition to this the serum of the blood of one animal may act as a destroyer of the blood corpuscles of another animal. In case of the loss of blood the better plan is not to inject blood, but to inject a solution of sodium chloride, because this solution is isotonic to the corpuscles. There are other forms of polyæmia, but most of these are discussed in pathology. The reverse condition is anæmia—the reverse of polyæmia or the reduction of the quantity of blood as a whole. A large quantity of the total blood may be lost by hemorrhage without any fatal results. In animals a loss of two to three per cent of the body weight is not fatal. While in man a loss of 4.5 per cent—that is not of the blood, but of the body weight—that is more than one-half of the entire blood, will prove fatal. It is estimated that in man a loss of 3 per cent may be recovered from. An injection of .9 per cent solution of sodium chloride after such severe hemorrhages, have the physiological effect of putting into rapid circulation the diminished number of red corpuscles and thus securing such a circulation as tends to preserve life and to restore its normal conditions. Females seem to bear the loss of blood better than men. This being due physiologically, to the more rapid renewal of blood in connection with menstruation.

Newly born children seem to be seriously affected by a small loss of blood, whereas in the adult life, one half of the blood may be lost before any serious results follow. Stout and aged people bear the loss of blood with less vigor. There seems to be a connection between the fat substances of the body and the fact that explains this—something will be said of this later. The more rapid the loss of blood, the more dangerous it seems to be. If the hemorrhage is not sufficient to cause death, the fluid portion of the blood and the blood salts are restored by absorption from the tissues,

followed by an increased blood pressure, the restoration of albumin and the formation, and increase in the number of red corpuscles. Regeneration—the reintegration of the blood—sets in in a few hours after a slight hemorrhage and in from one to two days after a severe hemorrhage. During the process of regeneration the number of corpuscles in the different stages of their development increases, that is developing corpuscles containing less than a normal amount of haemoglobin. That is the physiological and chemical property of these developing corpuscles.

In the cold blooded animals hemorrhage seems to have much less effect upon the life than in the case of the warm blooded animals; for example, the frog is able to live for a period without blood. Cohnheim washed out all the blood from the vessels of a frog with a solution of .75 per cent. of sodium chloride and filled the vessels—the vessels washed out—with this same solution. The frog continued to live for several days eliminating normally carbon dioxide. This experiment seems to indicate, physiologically, that the carbon dioxide is formed not in the blood, but in the tissues of the body.

In anæmic persons it is found that proteid composition is increased, resulting in an increased excretion of urea, whereas fat decomposition is decreased. This depends upon the diminution of carbon dioxide. One result said to follow from that is the theory that after the anæmic condition it is very easy to put on fat. You will find this principle to be a very old one. Aristotle, one of the old Philosophers, said that to put the cattle in anæmic condition, artificially, that they could be more easily fattened when recovering from this condition. It is not only so in the human, but also in the animal life. Among the abnormal conditions of the blood we find the presence of animal and vegetable parasites, most important, giving rise to abnormal conditions, which are discussed fully in Pathology. Some of these, especially the vegetable organisms have the power of multiplying very rapidly in the blood, and, as we have seen Physiologically, the blood may be rendered immune against these bacteria. That finishes the abnormal conditions of the blood.

SECTION VI. Variations in the Composition of the Blood Normally.

The blood is influenced by a great number of conditions including diet, age, temperament and sex. The dietary conditions will be referred to later in connection with the food.

AGE:—The fetal blood is very rich in solid matter, chiefly the red corpuscles. This does not say in what stage of development or growth these corpuscles are. This condition gradually diminishes until the close of the intra-uterine life. The amount of solid matter continues to diminish during the progress of childhood; increases during the adult life, and then again diminishes during old age.

TEMPERMENT:—In persons of a plethoric temperment—or somtimes called the sanguineous temperament— the amount of solid matter in the blood seems to be much larger, particularly in the red corpuscles.

SEX:—The blood of the male differs from that of the female, chiefly in a higher specific gravity of the male, on account of the fact that the male blood contains a larger number of red corpuscles; in the female it also varies in menstruation and during pregnancy, slightly increasing in the former condition and diminishing in the latter. In the latter condition, the specific gravity of the blood is much lower than in the normal female blood.

In the case of bleeding, the specific gravity of the blood—that is in hemorrhage that we spoke of before—is diminished, so much so that the flowing current of the blood from a wound diminishes as the flow takes place. This is due to the absorption of liquid from the tissues of the body. Physiologically this is connected with the conditions of thirst that usually follow the loss of blood. Water is absorbed in the tissues, and hence, gives the desire for water—thirsty condition. The composition of the blood varies in different parts of the body, arterial blood differing from venous blood, and venous blood differing according to the veins in which that blood flows. There are three special differences between arterial and venous blood.

1st. In the arterial blood we have a bright scarlet color, due to the presence of oxy-hæmoglobin, whereas in the venous blood, we find a dark purplish color, due to the deoxidation of the oxy-hæmoglobin.

2d. Arterial blood contains less carbon dioxide and more oxygen than the venous blood.

3d. Arterial blood coagulates more rapidly than venous blood.

In the venous blood there are said to be four different standards of blood.

1st. The normal venous blood. The other three are variations from this.

2d. Splenic venous blood—that is the blood, of course, in the splenic vein. This blood is generally deficient in the red corpuscles, containing a large amount of proteid matter and yielding a fibrin in case of coagulation above the average blood fibrin. There is also a large proportion of the colorless corpuscles and the plasma is deeply colored on account of the dissolved hæmatin. On account of the deficiency of red corpuscles, solid matter seems to be greatly diminished.

3d. Portal venous blood: The blood that is carried in the portal vein to the liver, coming from the gastric and mesenteric veins which contain the dissolved food elements absorbed during digestion from the stomach and the intestines, and also from the splenic vein; this portal blood combines the qualities of these two—that is, you have the characteristic of the splenic blood and also of the blood coming from the gastric and mesenteric veins. The blood carried in the gastric and mesenteric veins varies according to the digestive conditions—both of the food and of the organs of digestion. This blood seems to be deficient in solid materials chiefly in the red corpuscles. On account of the quantity of water absorbed it contains—that is Portal blood—a large proportion of proteids and gives a much less characteristic fibrin than the ordinary blood.

4th. Hepatic Venous blood. This is found to contain a smaller proportion of water, salts and proteid matter than the portal blood. At the same time it contains a much larger proportion of the extractives. Grape sugar for example, This grape sugar being found as a constant element, sometimes called the characteristic element of Hepatic blood. All of these variations in the standard of blood are Physiologically of great value in connection with the alimentary functions. They are mentioned here to bring them into the subject of blood, because we treat here of the general conditions of the blood.

SECTION VII. The Lymph and the Blood Glands.

It is a matter of discussion with Physiologists whether this subject should be discussed under the subject of the blood, or later. It seems to come in quite naturally here, because of the relations between Lymph and Blood. There is no other place where it could come, except in the discussion of the different functions of the body, unless it is to come in connection with the glands.

Lymph is a colorless fluid, resembling the blood plasma, and is found outside the capillary walls, filling the extravascular spaces of the body. All the tissue elements and the outside of the capillaries are said to be bathed in lymph. The entire body, except the epidermis and the epidermal structures, is supplied with blood vessels. The blood plasma filters through the capillary walls, together with white corpuscles and in some cases the red corpuscles. These pass into the lymph and bring to the tissues of the body nutriment and oxygen and carry off the waste. This lymph fills the extravascular spaces which open into the lymphatic vessels, which unite to form larger trunks, forming thus two main trunks: the thoracic or left lymphatic duct and the smaller or the right lymphatic duct. In this way a double interchange takes place from the blood to the tissues and from the tissues to the blood, the lymph acting as a middle man. When this is accomplished—that is this double interchange—a third stream from the lymph to the large lymph vessels carries away from the tissues such parts of the material coming from the blood vessels as the tissues do not, or cannot keep, and also such parts of the waste products from the tissues as are not taken up by the blood vessels. In this way the changes in the blood and in the tissues take place through the medium of the lymph, making it, therefore, most important in connection with the blood. Lymph is essentially the same as the blood plasma, containing the three blood proteids, the extractives, and also the salts. The proteids, particularly fibrinogen, are less in amounts in the lymph than in the blood. This lymph consists of a colorless fluid, containing leucocytes and small bodies of fatty substance, which are very numerous after meals. Formerly lymph was supposed to be derived from the blood plasma by a process of filtration through the capillary walls. In recent times this process of filtration through the capillary walls has been shown to be insufficient to account for the contents and the composition of the lymph. There are two physiological opinions on this subject.

1st. Those who explain the composition of the lymph as due to filtration—filtration through the capillary walls—and diffusion from the blood plasma.

2nd. Those who think that in addition to these two processes—filtration and diffusion—it is necessary to assume a secretory action on the part of the cells composing the structure of the capillary walls. So that, according to this, there are three fluid processes—the filtration and diffusion and the secretion—which would represent the metabolism of the lymph. At the present time it is impossible to say anything more on the subject than simply to quote these points as there are no characteristic points on either side to show that the one opinion is more physiologically correct than the other. Indications seem to point in the direction of the second opinion so far as we have reached—that is the process of filtration through the capillary walls and diffusion from the blood plasma and also the secretion in connection with the cells that are found in the walls of the capillaries. Blood takes in new supplies from the alimentary canal and the lymphatics. From the first it receives directly through the blood vessels or indirectly through the chyle, by the first of course, we mean the alimentary canal; from the second—that is the lymphatics, it receives the lymph—the characteristic lymph. Respiration gives a fresh supply of oxygen. And finally certain elements come to the blood from different parts of the body. These parts of the body that furnish these supplies being sometimes called the blood glands. This is not a very suitable expression because most recent investigations have shown that these ductless glands are not blood glands at all. Although it is not scientifically correct, it is better to adhere to it because they are so-called in all Physiologies.

These are six in number, (1) the lymphatic glands; (2) the glands of Peyer; (3) the Thymus gland; (4) the spleen; (5) the Thyroid body and (6) the supra-enal capsules. The lymphatic and the Peyer's glands, will be discussed later in connection with circulation and alimentation. All these glands resemble erch other in structure, being rich in protoplasm and adenoid tissue, and having many lymph corpuscles. They are also very vascular and they have no ducts, being what are called the ductless glands; they have been called blood glands; because they are supposed to be connected with the formation of blood. The whole lymphatic system is concerned in some way in blood formation. The lymph corpuscles are supplied by the lymph and the chyle. These are chiefly from the adenoid tissue of the lymphatic glands, being washed out by the lymph into the larger lymphatics, the chyle washing out the lymph corpuscles in the adenoid tissue of the villi. In this way the lymph corpuscles are constantly flowing into the blood and these are identified with the colorless corpuscles of the blood. These colorless corpuscles accumulate in the blood and in some way are connected with the formation of thered corpuscles. These colored corpuscles which exist in large numbers, in some way become disintegrated, this disintegration taking place in connection with the liver and the spleen. Phosphate of iron found in the bile is derived from the haemoglobin of the blood. In the spleen, also, large numbers of red corpuscles decompose the large protoplasmic cells inclosing the corpuscles and causing their descomposition. In order to supply the blood with fresh material, the process of blood formation goes on as a counteracting influence to decomposition.

The question as to the origin of the colorless corpuscles is one that has been greatly discussed in the field of physiology.

These colorless cells are the haematoblasts which are found in the spleen and especially in the red marrow of the bones. As found in these, the spleen and the red marrow of the bones, they are found to be colorless, granular, contractile bodies, very much like the leucocytes. The nucleus becomes a large corpuscle, the original blood plasmic cell is sometimes spoken of as the cell of Neumann. Later the nucleus is expelled from the large corpuscle and the rest of the cell that is outside the neucleus becomes filled with haemoglobin and forms the red corpuscles. In Mammals the red corpuscle is not therefore a modified nucleus, but it is a part of the substance of the Neumann's corpuscle outside of the nucleus. The original cell, as we said, was this Neumann corpuscle, the separation of this nucleus in the mammalian corpuscle from the rest of the substances of the corpuscle leads to the formation of the red corpuscle; the balance of that substance being connected in some way with what we find in the red corpuscle.

1st. The colorless corpuscles originate rapidly by the division of the lymphatic corpuscles in the lymphatic glands and also in the Peyer's glands. In the spleen, also, the process of cell multiplication goes on rapidly, the delicate andenoid tissue of this organ being full of pale corpuscles, and the splenic vein being filled with blood that is rich in the white cells. The red bone marrow is the seat of the most rapid formation of the colorless corpuscles. It contains —that is the red bone marrow—fibrillar connective tissue, fat cells, leucocytes and great cells. We find these sometimes spoken of in physiology as giant cells. These giant cells are large cells of irregular shape consisting of protoplasm and nuclei. In the red marrow we find the haematoblasts—that is the cells of the protoplasm, yellow in color. These form the red blood corpuscles. These large nucleated cells are found very abundantly in early embryonic life. Up to the fourth week of that embryonic life, only such nucleated cells are found, that is, no other cells are found in the human embryo up to the fourth week. After this the nucleus becomes smaller, and, in a short time the nucleus entirely disappears, and the corpuscle assumes its biconcave form. The nucleated forms being found very rarely at the close of the uterine life. After birth the red corpuscles are formed from these nucleated colorless cells, especially in the red marrow of the bones. In the uterine and early extra-uterine life the thymus, thyroid body and the supra-renal capsules are supposed to have blood forming functions; while later in life it is probable that their chief function is to use up and divide into simpler bodies the elements of the blood—that is, to prepare for the blood and to form the elements of the blood itself. As these bodies are ductless glands, those new matters cannot be secreted, and, hence they pass by a reabsorption into the blood again for still further use. These bodies, the thymus, the thyroid and the supra-renal capsules have the function of disintegration, but differentiate with the action of these glands of the blood that unite and back up the process of reintegration into the blood once more.

2d. The spleen is undoubtedly a blood gland, whatever other functions it may discharge. The spleen pulp consists of a mesh-work of delicate fibers of adenoid tissue which hold in the meshes of this pulp, the lymph corpuscles, and also the free or liberated red corpuscles. The spleen seems to discharge a double function. (1) That of forming corpuscles, and (2) of destroying the colored corpuscles. The spleen is also the seat of other operations, such as the decomposition of albuminous compounds and also of acid formations. That is still in line you will notice with the functions of the spleen as a destroyer or decomposer. The spleen, however, can be dispensed with entirely. It has been removed from the body and this removal has taken place without any great disadvantage to the vital system. There is a slight disadvantage, of course, temporarily, but when the local temporary disturbance is removed there is no permanent disadvantage following. In this case of the removal of the spleen it has been found that the lymphatic glands and the red marrow of the bones become more abundant with the colorless cells, and hence more active in the formation of the blood corpuscles. The lymphatic glands by some kind of functional sympathy discharge the spleen function as well as their own function.

3d. In the last stages of the uterine life and the first stages of the extra-uterine life the active growth of the tissues takes place and a large supply of blood corpuscles is necessary. In order to assist this active development of tissues and of blood corpuscles, the thymus gland seems to assist the red marrow of the bones, the lymphatics, and the spleen in the formation of red corpuscles. Later in life after this rapid development ceases the thymus gland becomes absorbed, and, in the case of man finally disappears when manhood is reached.

4th. The thyroid gland. In the early uterine life this thyroid has a duct which opens into the foramen caecum of the tongue, but this duct, like the thymus gland, disappears. Each lobe shows closed sacs which are lined by layers of epithelial cells; these cells being filled with fluid and also the leucocytes and the red corpuscles, partly disintegrated and also partly decolorized—deprived of color. This thyroid gland, if it is greatly enlarged, gives rise to abnormal conditions, two in number, Goitre and cretinism, the latter of which is associated with a form of idiocy. Some say the removal of this gland results in mental weakening—that is, it produces an artificial cretinism. After its removal certain changes have been observed bearing upon the gland function; for example, the red corpuscles are found to be diminished in number and the white corpuscles increase in number. The salivary glands enlarge and the parotid gland which is normally serous, begins to secrete mucin this mucin being found even in the blood. This furnishes the only evidence that we have that the thyroid is a blood forming body.

5th. The supra-renal bodies. These bodies are found to be large in the uterine life, at the end of the third month of the uterine life being as large as the kidneys. The medullary part which at first is outside of the cortical part—these represent two parts of the supra-renal bodies in the fetal life—afterwards is enclosed by it, containing albuminous bodies and pigment. A watery mixture of these supra-renal bodies gives coloring matter such as we find in the blood. McMunn, a physiologist who investigated this subject, has observed that the spectrum of the supra-renal bodies gives bands of reduced haematin, hence, he claims that their function is to pick out of the circulation worn out coloring matter with their proteids and to separate them so as to prepare them for integration in the formation of new coloring matter. An abnormal condition associated with these bodies is spoken of as Addison's disease, which is the result of these bodies not discharging their proper functions. This disease consists of the sallow or bronzed tinting of the skin, accompanied by giddiness—in its physiological sense—vomiting and breathlessness.

6th. The pituitary body or hypophysis cerebri, although not a blood forming gland, must be classed with these other glands on account of its supposed function of aiding the blood supply to the brain. The supply of new material furnished to the blood may be summarized as follows: (1) By vascular absorption through the alimentary canal; for example, water, sugar, peptones and salts. (2) Lacteal absorption, also through the alimentary canal; for example, water, salts and fats. (3) Through the skin; for example, water anb certain volatile and soluble matters. (4) Through the mucous membrane of the lungs; for example, oxygen, aqueous vapors and volatile matters. (5) Through the lymph or the closed sacs into which the fluid matters have been effused. (6) The lymphatic glands, the mesenteric glands and the other dlood glands; certain protoplasmic elements and lymph cells in which certain exchanges take place between the lymph and the blood; for example, the colored corpuscles of the blood are formed from these lymph elements, or protoplasmic cells. That finishes the subject of the blood.

CHAPTER III. CIRCULATION OF THE BLOOD.

SECTION I. General Statement.

By the circulation of the blood is meant that the fluid during life is contained with ina continuous system of elastic and contractile vessels, that this fluid moves along this continuous course, always returning upon itself in the course of its flow, and that this blood, whatever may be its constitution, moves along in a certain definite direction, never in the opposite direction.

Harvey, the discoverer of the blood circulation, says, that a perpetual movement of the blood in a circle is caused by the heart beat. The discovery of the blood, by Harvey, dates from 1616. This continuous system consists of the heart which is at the commencement of the arteries and at the termination of the veins; the arteries terminating in capillaries out of which arise the veins. The heart is a double organ, each half consisting of an auricle and a ventricle, the right half containing the blood as it is returned from the body to be passed on to the lungs, and the left half containing the blood passed from the lungs to be sent out into the body. The circulation of the blood is said to be two fold; 1st. Pulmonary circulation from the right side of the heart by the pulmonary artery to the lungs, through the lung capillaries and back again to the left

side of the heart by the pulmonary veins. 2d. Systemic circulation from the left side of the heart through the aorta and the arteries to the tissues by the capillaries, and thence into the veins and back again to the right side of the heart. The circulation of the blood can be followed from the right auricle to the right ventricle, through the right auriculo-ventricular opening protected by the tricuspid valve. From the right ventricle through the polmonary artery, through the lung capillaries into the polmonary veins which give it passage into the left auricle. From the left auricle to the left ventricle through the left auriculo-ventricular opening protected by the mitral valve; from the left ventricle into the larger arteries, the intermediate arteries and the arterioles into the tissues and the different organ capillaries. From these minute capillaries, the blood passes through the veins, which, at first are small, gradually increasing into larger trunks till it reaches the superior and inferior venae cavae, these constituting the openings into the right auricle. These vessels have walls, all of which are more or less elastic and on being filled with the blood they are subject to distension. This distended condition gives rise to the tension which may be varied at any point by the application of pressure.

This pressure applied at any one point produces a movement of the liquid in the direction of the lesser pressure, and as these vessels represent a closed tubular system, the liquid under such pressure circulates the valvular, mechanism being utilized in order to determine the direction of the blood flow. In the living body the contraction of the muscular walls of the right ventricle narrows its cavity and forces the blood out from the right to the left side of the heart through the pulmonary capillaries which are in immediate contact with the respiratories of the lungs. The contraction of the muscular walls of the left ventricle also narrows its cavity, forcing the blood from the left to the right side of the heart, through the systemic capillaries of the body. These two contractions are simultaneous. Each contraction furnishes a force which is utilized as energy being supplemented to a slight extent by the energy which arises from aspiration and also from the contraction of the skeletal muscles. This force drives the blood into the arterial system increasing the arterial pressure, the arteries in turn driving a part of the blood into the capillaries which convey the blood to the veins, tending to equalize the pressure between the arteries and the veins. The pressure never becomes equalized, because if the pressure should become equalized the blood would be evenly balanced between the arteries and the veins. Equilibrium would result in the stopping of the circulation. As the veins empty back the blood into the heart the heart once more contracts and drives more blood into the arteries, thus increasing the arterial pressure and preventing at any one time an equilibration of pressure between the venous and the arterial circulation. If equilibrium were produced in the blood it would remain stagnant, as a certain amount of the blood in the arteries and in the veins in the venous system there cannot be any force of movement to cause them to circulate because the pressure would not be greater in the arterial system, the blood would not be pressed forward, and hence we would not have circulation. In this way we have, 1st the circulation itself, determined and definite, and 2d, the direction of the circulation is also definite and it is always determined toward the lesser pressure. The blood which is the internal medium on which the tissues live, thus circulates through the entire system, mainly through the capillaries whose fine walls are so delicate that certain elements from the circulating blood pass through the capillaries to the tissues outside, while certain elements of the tissues pass through the walls into the blood, thus keeping up a constant interchange of elements between the blood and the tissues by the medium of the lymph. This constant interchange accounts for the fact that there is scarcely ever, if any, appreciable change in the volume of blood. There is as much absorption one way as the other and the difference of the volume of absorption would cause an abnormal condition, and so we have in the venous circulation, no difference in the volume of the blood, from what we find in the arterial circulation. If there is a difference it is very slight. The vascular mechanism is so designed that the blood must pass through the minute vessels where the chief work of the blood is done—that is in the capillaries, in such a way as to secure the efficient interchange of these elements. From this general statement we find that the circulation consists of four distinct elements. (1) The heart, whose chief function is to drive the blood into the arteries, through the arteries into the capillaries and thence through the veins into the heart. We speak of this first function, because there are other functions, of course, which the heart discharges. This is the chief one, of course, in connection with the circulation. (2). The arteries, whose chief function is to convey the blood from the heart to the capillaries. (3) The veins, whose chief function is to convey the blood from the capillaries to the heart. (4) The capillaries, including the minute arteries, ending in the capillaries and the minute veins, beginning in the capillaries, whose chief function is to perform the double interchange we have just spoken of, between the tissues and the blood, and the bloodand the tissues.

To understand the circulation is to follow out the blood in its course along this blood path noticing the phenomena manifested at each point and the influences bearing upon the circulation at any one point and on the circulation in general. For convenience the circulation of the blood may be divided into three parts. 1st. The heart as the center of the vascular mechanism. 2d. The blood vessels, and 3d the general circulation, its mechanism and action, including the blood and lymph. Some Physiologists discuss first the capillary circulation because the all important phenomena in connection with blood and tissue interchange are found there. It is better however in systematically discussing the circulation to commence at the great force which represents the center of the circulatory system.

SECTION 2. General Physiology of the Heart.

I, THE HEART AS THE CENTER OF THE VASCULAR MECHANISM.

The heart is a hollow muscle, covered on the external surface with a serous membrane, the pericardium, and on the interior is lined also with a serous membrane, the endocardium, continuous with the lining of the blood vessels. The heart is thus enclosed in a membranous sac and lies behind the sternum and costal cartilages, the base rising upward, falling backward to the right and reaching from the fifth to the eighth dorsal vertebra. The apex reaches downward and forward to the left and its beat is felt in the living subject in the interspace between the fifth and sixth ribs slightly below and to the central side of the nipple. Thus the heart lies obliquely in the chest cavity projecting into the left of the cavity.

The heart is composed of a special tissue together with connective tissue, vessels, that is, blood vessels, lymphatics, nerves and ganglia. The cardiac fibers are intermediate, both in structure and in function, between the non-striated and the striated fibers. The muscular mass of the heart is called myocardium. A considerable mass of fibrous tissue and fibro-cartilage is seen at the base of the heart between the openings of the aorta and the two auriculo-ventricular orifices from which pass different processes forming the basis of those tendonous rings at the auriculo-ventricular and the arterial openings. To these bands or rings are attached the muscular fibers laid out in layers. In

the embryonic life the heart is tubular in shape, or form, its fibers being arranged in an external circular and an internal longitudinal form. As the heart develops during the embryonic life the longitudinal form becomes curved, the venous portion being doubled over upon the arterial portion, the auricle being in a dorsal position to the left of the ventricle. Later in its development the single cavity of the auricle and the ventricle, such as we find in the embryonic life, becomes divided into two, when the septum is formed, dividing the original single chamber into two In the case of the auricle, the fibers remain less complicated than those of the ventricle, the fibers of the ventricles being arranged in a spiral form. The fibres of the auricle are perfectly distinct from those of the ventricles, being separated by tendinous rings, these fibers forming two layers; an inner longitudinal set for each auricle and an outer transverse set for both auricles. There are said to be seven layers of fibers constituting the walls of each ventricle, three external layers, three internal layers and a middle layer. These layers are so arranged that the first external layer is continuous with the last internal layer, the second external with the second last layer of the internal, etc. The pericardium is a conical shaped sac; its base resting on the diaphragm and its upper part encompassing the roots of the larger vessels. There is an outer layer of tissue and an inner layer of serous membrane which covers the outer surface of the heart In the interspace between these two layers is found the peri cardial fluid. The endo-cardium or the lining membrane of the heart consists of connective tissue and elastic fibers forming a strong wall which round about the openings into the vessels is very strongly developed. Among the elastic fibers are found scattered bundles of unstriped muscular fibers. The fibers of this muscle being used as a means of resistance to the heart contraction and also a resistance against the extreme pressure on the endocardium. Functionally, the heart is a muscular and a valvular pump working on mechanical principles, the force being supplied by the contraction of the muscular fibers, the beats, or strokes of the heart being repeated so many times per minute—72 normally in man, which corresponds to the pulse. The heart is so furnished with valves that at each beat of the heart a quantity of blood is forced from the left ventricle into the aorta and the blood carries with it a certain amount of force sufficient to drive it along the vessels, the same quantity of blood being received at each heart beat from the veins into the right auricle. The action of the heart is thus partly mechanical and partly vital The vital action is determined by the causes which produce the rhythm, power or force, and general character of the beat, whereas, the mechanical action is determined by the frequency, force and general character of the heart beat together with the amount of blood that is forced out at each beat. The contraction of the auricles is quite independent of the contraction of the ventricles and the heart rhythm—that is, the frequency of the heart beat—being normal the auricular and ventricular contractions correspond with each other. The character of each beat is determined by the changes which take place in the tissues of the heart When the heart grows feeble, or when the heart is dying the auricle beats several times to every beat of the ventricle till at last only auricular contraction is found taking place, the right auricle being the last portion of the heart to die, hence called the ultimum moriens. The contraction of the circular fibers around the openings of the veins into the heart, causes the blood to pass into the auricles and the constriction of these fibers prevents regurgitation of the blood, these constricted fibers acting the part of valves. The double layers of fibers in the auricles upon contraction produce a uniform diminution of the cavity of the auricles. The spiral form of the fibers—you remember that was mentioned in connection with the ventricle walls—

in the walls of the ventricles upon contraction give to it great force, so that the blood can be driven out with great force. The valvular arrangement is of great value, physiologically, in connection with the action of the heart. The tricuspid valve protects the right auriculo-ventricular opening. The tricuspid valve consists of three flaps, hence, the name, tricuspid valve, of fibrous and elastic tissue covered on the inside with endo-cardium—the same as in the lining of the heart. These surround the opening and are kept in place by the chordæ tendineæ. The bicuspid or mitral valve protects the left auriculo-ventricular opening and consists as its name indicates of two sections or segments of a pointed character and of the same composition as the tricuspid flaps. In the auriculo-ventricular valves we find the striated muscular fibers, the fibers extending from the auricles to the sections or segments of the valves. In this way the valves become shorter at the base and so a larger orifice is presented for the passage of the blood into the ventricles—these minute details being functionally of great importance. At the base of these segments or cusps there is a layer of concentrated fibers which act with a constrictive force towards the base of the valves. The aortic and pulmonary orifices are protected by the sigmoid or semilunar valves. Each of these valves consists of three semilunar segments and each segment or cusp is bound by its external surface to the arterial wall, its free surface or margin reaching, projecting inside the vessel. These segments consist of fibrous tissue covered with the endo-cardium—the same as the membranous lining of the heart. Opposite each semi lunar cusp is a thickening of the vessel called the sinus of Valsalva—this is a very important function in connection with the circulation of the blood. These sinuses in the aorta are arranged one of them anteriorly and two of them posteriorly.

From the anterior rises the right coronary artery and from the left posterior the left coronary artery. The vessels which furnish blood supplies to the heart substance—that is these arteries supply the blood to the heart substance. It is probable that during the contraction of the ventricle the semilunar valves do not cover the openings of the coronary artery. According to Sandborg these semilunar valves close just after the ventricles have begun to relax. The vessels of the myocardium are very numerous representing the great activity of the heart substance.

Some physiologists have ligatured the coronary arteries in dogs and found that in two minutes cardiac contractions give place to twitchings of the muscle fibers and then the heart ceased beating. Ligature of the one artery affects first the ventricle, then the other ventricle and finally the auricles.

In the case of hardening of the coronary arteries found in old age, there is diminished action with heart weakness. This hardening is sometimes called ossification of the heart and induces if it does not produce death finally, from the cessation of the heart simply due to old age. Death may occur suddenly from quick cessation of the heart's action. The size of the heart is roughly estimated according to Lænnec to be about equal to the closed hand. In the child, until the body reaches 40 kilograms, in weight the heart is about 5 grams to one kilogram. When the body weight is from 50 to 90 kilogams the proportion is 4 grams to one kilogram, and when the body weight is 100 kilograms the proportion is 3.5 grams to one kilogram. The proportional heart weight to body weight according to this would be 1 to 150 or 1 to 170, varying with the advance of age, as the auricles increase in strength. The mean weight of the heart in the adult male is from 309 to 312 grams. In the female 255 to 274—smaller in size, physiologically, at least, the average about 270. The two ventricles seem to be about equal in their capacity, although after death the post mortem heart practically seems to indicate that the right ventricle is larger than the left ventricle, but this is due to the fact that the left ventricle is usually empty of blood, while the right ventricle is filled with blood. The wall of the left ventricle is much greater in thickness than the wall of the right ventricle. The thickness of the left ventricle at this middle portion is about 11.25 to 11.40 millimeters; in the female it is slightly smaller, 11.15. In the case of the right ventricle the average thickness in the male 3.8 to 4.1 and in the female 3.6. These represent the physical properties connected with the heart.

SECTION III.—The Physiology of the Heart's Action.

If the hand is placed on the chest between the 5th and 6th ribs below and internal to the central part of the left nipple an impulse is felt. The method of examining the heart in this way is called palpation. If the ear is placed over the heart or in connection with the stethoscope certain sounds are heard, the frequency and the character of which are of great physiolgical value. This method of examination is called auscultation. By means of percussion the exact extent, size and condition of the heart may be ascertained as well as its relation to the lungs and the presence or the absence of the fluids in the pericandium. This method is called the method of percussion. Certain instruments are also used for the purpose of registering the action of the heart. The movements of the heart are found to consist of a series of contractions occurring successively with a certain rhythm. The state of contraction is called systole while the condition of relaxation is called diastole. The two auricles contract and relax simultaneously, followed by simultaneous contractions and relaxation of the ventricles. This gives us a systole and diastole of both the auricles and the ventricles.

As we have seen the heart is a double organ with an auricle and a ventricle in each lateral half. In each part the contraction and relaxation of the auricle is followed by the successive contraction and relaxation of the ventricle. Following this succession of contractions and relaxations there is said to be in diastole—not a part of the heart, but the whole heart is said to be in diastole. In this way we have three periods, the systolic; the diastolic; the diastole of the whole heart. This series of actions beginning with the auricular systole and closing with the diastole of the whole heart is called the period of revolution or the cardiac cycle. The auricular systole occupies 1-5 of the entire period of revolution. One-fifth would correspond with the systole, the ventricular systole, 2-5 of the entire period of revolution followed by the period of rest, which occupies the balance of the 5·5, which would be 2·5. These correspond with the three periods of the cardiac cycle. The auricular systole immediately precedes the ventricular systole and the commencement of the ventricular systole is simultaneous with the beginning of the auricular diastole. The auricles and the ventricles being thus in diastole 2·5 of the whole period of revolution Chauveau and Marey, two physiologists who have investigated this subject, have made use of the cardiac sound in connection with the tracing of the movements of the heart of a horse—not a human heart in this case. This cardiac sound is very much like the surgeon's sound which is used in connection with stone in the bladder.

This sound is passed into the right side of the heart through the jugular vein and the superior vena cava—the horse is supposed to be still living—the lower end of the sound with its elastic bag being passed down into the ventricle while the upper end of the sound, also with an elastic bag, remains in the auricle. Each bag is placed in connection with a recording instrument—in this case it was tambour of Marey—and along with the cardiograph which is applied externally over the apex of the beating heart, they are attached to a revolving cylinder. blackened, of course, the varations found in connection with the elastic bag being regarded as a tracing on the black cylinder. In this case there are three tracings present, the one representing the lower elastic bag, one the upper elastic bag, and then the one that represents the cardiograph from the apex of the heart. As a result of this experiment the following points have been noted physiologically.

1st. Ventricular contraction is more sudden than auricular contraction. The tracing gives us a ventricular set of curves and an auricular.

2nd. The ventricular contraction lasts longer than the auricular contraction.

3d. Auricular contraction and relaxation occupies almost equal periods, whereas, ventricular relaxation is almost twice the length of ventricular contraction.

4th. As a result of what is contained in the third point, auricular movements are found to be uniform and present a wave like appearance, whereas, the ventricular are irregular and sporadic.

5th. Auricular movement precedes the ventricular and the empulse of the apex against the chest wall occurs during the ventricular movement.

6th. Auricular contraction influences the pressure in the ventricle.

7th. During the ventricular contraction there are oscillations of pressure, influencing both the auricle and the ventricle—there are no oscillations in the auricular contraction, but there are in the ventricular and those oscillations are so large that they influence not only the ventricle but also the auricle. These points present the main features in connection with the changes that are found in the cardiac cycle. Although these experiments were made on the horse, the investigation in connection with the same subject indicates that there is no marked difference from this in the human subject. But these results are as we find them in the horse.

When the auricles pass into perfect diastole, the blood is pouring through the vena cava and the pulmonary veins into the auricles. The auricular cavity being enlarged while auriculo ventricular valve protects the orifices. This distended condition of the auricles is due in part at least to the pressure of the superior and inferior vena cava and also of the pulmonary veins, this pressure being greater than the internal auricular pressure. It is also due in part to the suction action of inspiration drawing the blood from the veins out side of the chest to those inside of the chest and thus promoting circulation towards the heart—not into the heart but in the direction of the heart. While this takes place the two ventricles are being filled with blood through the auriculo ventricular openings. As soon as the auricles are completely distended, which takes place before the ventricles are distended because the ventricular capacity is greater than the auricular capacity, the auricular systole then begins by the contraction of the auricular walls and the emptying of its cavity—auricular cavity—and by the contraction of the circular fibers of the orifices of the venous openings into the auricles. These movements rapidly pass over the auricular walls, transmitting the wave of contraction on toward the auriculo ventricular orifices. This wave of contraction running along the auricular wall drives the blood in the direction of least resistance—that is of course. out of the auricle into the ventricle the ventricle being partially filled with blood already and gradually passing out of the state of relaxation.

The blood cannot pass backwards on account of the venous pressure and the contraction of the orifices of the veins which marks the commencement of the auricular systole. There is, however, a temporary arrest of the blood flow into the large veins. This indicates that the auricles not only act as a medium for the transmission of blood from the veins to the auricles but also that these auricles act as rythmic cavities which preserve the pressure in the veins, lessening by their distension the pressure in the veins, which tends to increase during the ventricular systole, and increasing the pressure by contraction when venous pressure tends to diminish towards the close of the ventricular diastole.

In the case of the auricles and the ventricles we find during their disastole a suction action which is feeble, however, as compared with the force of pressure. Immediately following the auricular contraction is the ventricular systole, the quantity of blood driven by the auricular systole into the ventricles which have alreadybeen partially filled during the auricular diastole, being sufficient to fill the cavities of the ventricles. While the blood is flowing out of the auricles into the ventricles, the auriculo-ventricular valves become slightly horizontal, this being partly due to the contraction of the longitudinal fibers extending from the auricle into the segments of the valves. On the contraction of the walls of the ventricles the surfaces of the auriculo-ventricular valves come together thus preventing the cusps from being injected into the auricle. The papillary muscles (musculi papillares) contracting simultaneously and tightening the chordæ tendineæ which are attached to the ventricular side of the valves. The cusps are closely pressed together along their margins on account of the fact that the chordæ tendineæ of one papillary muscle passes to the adjacent edges of the two flaps. By this means the tricuspid valve on the right side and the mitral valve on the left side are kept closely and firmly closed, the blood being prevented from regurgitating because the orifices are completely and securely closed. When the ventricular systole begins, the semilunar valves of the pulmonary artery are closed, but as the pressure of the ventricle upon the blood increases, the semilunar valves are forced open and the blood passes into the pulmonary artery from the right and into the aorta from the left ventricle. In the ventricles the pressure is highest at the commencement of the contraction when the pressure is said to be positive. During contraction it reaches its lowest point, becoming negative at the close of the contraction of the systole. At this time there is a suction action due to the emptying of the cavity by the sudden and forceful expulsion of the blood into the aorta and the pulmonary artery. The pressure is negative, also, during the diastole that immediately follows. When the blood pasess from the ventricles, the semilunar valves are forced open, their cusps being stretched across the sinuses of Valsalva, that lie behind each cusp without being pressed against the vessel wall, the reflux current of the blood preventing the contact of the cusps with the vessel wall, and as the amount of bloodls, greatly increased on account of the blood that is expelled from the ventrice is and the blood present in the vessels before the expulsion, the pressure is increased in the vessels and the vessel walls become distended. When the last of the volume of the blood leaves the ventricles a negative pressure appears behind the blood current, resulting in a reflux current from the artery to the ventricle. This reflux current assists, according to some Physiologists, causes the closure of the valves behind the blood. The ventricular systole now closes after the ventricle has continued in the state of contraction for a short period, the muscular walls relax, the ventricle returns to its original form and position. With the beginning of the relaxation of the ventricles, the auriculo ventricular openings again open and the blood passes from the auricles into the ventricles; at the same time the delicate arterial walls yield to recoil forcing a part of the blood back towards the ventricular cavities in which the blood pressure is much less than the arterial pressure, as they pass into diastole. This quantity of blood that it forced back by reflux pressure finds a lodgment in the sinuses of valsalva, and the pouches of the semilunar valves, closing the valves themselves, thus preventing, in this way, the flow of blood backward into the ventricles. From the close of the ventricular contraction until the auricles are again filled with blood all the heart cavities are dilated, the cavities, themselves, being gradually filled with blood This is the period of rest or pause during which the whole heart is supposed to be resting.

SECTION IV.—Changes in the Heart.

The changes in the active beating heart are so rapid that they cannot be observed so as to form any adequate conception of the exact nature of these changes. The ventricles are constantly changing in their form. For example: While the blood is pouring into their cavities from the auricles through the auriculo-ventricular openings during the increase of the pressure on the walls; while the wave of pressure contraction is passing along the walls; while that pressure is acting upon the blood contained within these cavities in driving it out into the arteries; and finally during the relaxation of the walls after the expulsion of the blood.

During systole the ventricles become tense, being larger during diastole, the difference in size being measured by the volume of blood that is driven out. The whole contents are driven out at each stroke, the emptying taking place from the apex of the cavity towards the opening of the artery. While this takes place there is a change from the hemispherical form with an elliptical base to a more conical form with a circular base, the transverse diameter being diminished and the antero posterior diameter increased. This increased fronto-posterior diameter and decreased transverse diameter changes the form of the base of the ventricle. During diastole the base is elliptical with the long axis from side to side, frontally being convex and posteriorly flattened. During the systole the base becomes circular, the whole base being contracted and thus rendering more efficient the action of the tricuspid and the mitral valves. Ludwig and Hesse, two Physiologists, have made experiments in this connection on the heart of the dog. They distended the living heart of the dog until it dilated under a pressure equal to the arterial pressure. The ventricles are in the diastole and the auricles continue to beat. A plaster cast is made of the ventricles in this state, giving a mold of the diastolic condition of the heart. In order to obtain the systolic phase of the heart, a living heart emptied of its blood is sndde ly plunged into a hot solution of potassic bichromate, the solution is at temperature 50 degrees C., when the heart gives a strong final contraction remaining permanently in this rigor condition, under the influence of coagulation. In this state a cast is made which represents the systole phase. In order to obtain the heart cavities, two hearts were taken, filled with blood; the one filled with blood is put into a cold solution of patassic bichromate, causing the hardening in diastole, while the other, filled with blood is put into a hot solution of potassic bichromate. Casts were then made of the cavities of the heart. As a result of this experiment, it was found: 1st. In diastole, the ventricle is hemispheroidal, the apex circular, the posterior surface flatter than anterior surface; the base an ellipse, its greatest diameter being from right to left, and its shortest diameter from apex to base. The heart assuming an inclination towards the apex. 2nd. During the systole the apex becomes pointed; the ventricle assuming a conical shape, the base is circular, and its transverse diameter is diminished so that from apex to base is longer than the diameter at the base. The inclination of the heart has entirely dissappeared, the apex being now almost exactly opposite the center of the base. The heart is thus decreased in all its diameters except one, this is its perpendicular,—not included at any angle. The arterial openings are scarcely affected if affected at all. The auriculo ventricular orifices, however, are diminished. In this way the fibers of the heart, during the systole, contract at these orifices, assisting the closure of these valves and preventing the regurgitation of the blood.

These changes in form involve necessarily changes in position. During systole the ventricles are inclined toward the head and the median line, while the base of the ventricles recedes from the back, moving toward the apex. This base movement is followed by a lengthening of the aorta, the pulmonary artery causing in all probabilily the descent of the base in the contracting ventricles. The apex remains still in contact with the chest wall. During diastole the ventricle becomes soft and distended, the changes taking place being exactly the reverse of those taking place during systole which I have just mentioned. Cardiac impulse: If a hand is placed on the chest a shock or impulse may be felt along with each beat. In a human subject this impulse is felt in the fifth left intercostal space about two inches below the nipple and about one inch to the left of the sternum. This impulse is synchronous with the systole of the ventricle and is produced by the apex of the ventricle being firmly pressed against the the walls of the chest from which it is separated during the period of rest by the free surface of the lungs. This impulse is a distinct result of the hardening of the ventricle during the systoles the impulse itself being the result of the apex brought out into sudden contact with the chest wall, the impulse being conveyed through the chest wall to the surface of the skin. During systole the apex is brought into close contact with the chest wall by the movement of the ventricle toward the front, on account of which it becomes hard and tense. The ventricles, during systole, contract; the contraction of the cavities producing a pressure that is greater than the aortic and the pulmonary arterial pressure. As a result of this, the ventricle hardens, sudden pressure being assisted by close proximity to the chest wall, imparting a shock to the chest wall and also to the diaphragm. By the use of the cardiograph, this impulse may be traced. If the cardiograph is placed over the spot where the impulse is strongest the lever of the cardiograph rises during the ventricular systole and falls when it passes off. If the lever button is placed slightly away from the point of the strongest impulse, the lever will fall instead of rise during the ventricular systole, because away from the point of impact or strongest impulse the ventricle instead of coming into close contact with, retires from the chest wall and pericardial attachments of the mediastinum draws the chest wall after it.

In the space which becomes protruded by the impulse, the soft parts are found to be slightly drawn in, this attraction, caused by the lessened size of the contracting ventricles, being called the negative pressure. During the ventricular systole, the heart-form changes. During rest the heart is an oblique cone with an elliptical base, during systole it becomes regularly conical and the base becomes circular. During contraction the apex inclines upward and forward, being driven into the intercostal space, the ventricles turning on the long axis from left to right partially exposing the left ventricle. This twisting motion gives the impulse which is produced by the contraction of the obliquely placed fibers of the ventricles drawing up the apex, this movement being assisted by the spiral form of the aortic and the pulmonary arteries. It has been stated by some Physiologists that the impulse is partly due to the reaction of the ventricles, producing a recoil when the cavities are emptied of blood so that the apex is pushed outward and downward. Other Physiologists ascribe the impulse in part to the elongation of the aorta and pulmonary artery on account of which the apex is pushed outward and downward toward the chest wall. These actions may assist in producing the impulse, but the main cause is the twitching movement of the ventricles. That this twitching movement is the cause of the impulse is evident, (1st), from the fact that the impulse takes place, even when the heart cavity is empty of blood; as, for example, in case of severe hemorrhage. Even in this case—of severe hemorrhage—the ventricle seems to harden and this hardening changes the direction of the heart, turning it around and producing a twitching against the cavity of the chest wall. (2d). This is still more evident from the fact that an empty heart entirely removed from the body and placed upon a table or some flat surface raises its apex as it hardens in the systole, the same impulse being felt in the case of the heart under these conditions if the finger is placed over the rising apex, proving the fact that it is a change in the heart itself—not the question of the presence of the blood and not the question of recoil, but simply the twitching movement of the heart itself.

In order to produce the tracing of the apex beat, or a cardiogram—(the instrument is the cardiograph and the tracing on the instrument is the cardiogram,) various instruments called cardiographs have been invented. The improved cardiograph of Marey consists essentially of a tambour with a button attachment to the membrane, which is applied over the apex beat. The motions of the air inside the capsule—in this case it is air motion—are communicated by means of a tube to a recording tambour. The tracings which are obtained give distinctly the contraction of the auricles contracting in the direction of the axis of the heart from the right upwards toward the left downwards and causing the apex of the heart to move slightly towards the intercostal space. Smaller contractions give slight curve elevations. These smaller contractions being due to the contraction which takes place at the ends of the veins and the auricular appendages. Then follows the curve representing the greatest impulse which is cau ed by the contraction of the ventricles. This contraction being simultaneous with the first sound—these sounds will be discussed in connection with the cardiac sounds. The curve then rapidly falls when the ventricles relax, the blood in the aorta and the pulmonary artery being driven back by the recoil of the arterial walls, thus closing the semilunar valves. This impulse is communicated to the apex of the ventricles causing oscillation of the intercostal space. It would seem from the tracing of the curves that the aortic and pulmonary valves do not close simultaneously—the aortic valve closing first and then

about 1-100 of a second later the pulmonary valve. This difference is due to the greater aortic pressure—the aortic is greater than the pulmonary pressure and in this case the aortic closes sooner than the pulmonary valve. The tracings as found by Landois and Marey by his improved cardiograph seems to come very much like that; that is, the tracing which represents the normal movements or movements in connection with the condition of elements in the cardiac cycle.

The heart seems to exist chiefly for the purpose of exerting a pressure upon the blood in its cavities so as to secure the normal circulation. It is difficult to state these movements because the mercurial manometer fails us in this case. The most convenient instrument to use is a long tube open at the top end and filled with a solution of sodium carbonate. This tube may be introduced through the jugular vein into the right auricle and the right ventricle, and it may be introduced through the carotid artery and the aorta into the left ventricle. By establishing a connection between this tube and the mercurial manometer, in this case it is the maximum and minimum instrument, records may be taken of the pressure of these three cavities; the right auricle, the left ventricle and the right ventricle. In this case we get the maximum and minimum pressure attained in each one of these cavities. As a result of this it is found that the maximum pressure in the left ventricle is greater than the normal pressure in the aorta, that the maximum in the left ventricle is also greater than the maximum pressure in the right ventricle and in the right auricle the pressure is greatly diminished. In connection with the minimum records it is found that there is a negative pressure, that is, a pressure less than the atmosphere. This negative pressure may be partly due to aspiration in the respiratory processes but even when we take account respiration it is found that there exists still a negative pressure, at least, a negative pressure in the left ventricle which is very distinctly marked. This means that at some point in the cardiac cycle there must be a negative pressure normally. This negative pressure may arise in one of two ways—

1st. When the blood is driven out very quickly from the ventricle into the aorta a negative pressure seems to arise. This pressure partially accounts for the closure of the semilunar valves and therefore, this negative pressure would be greatest at the orifices of these valves. The manometer however indicates that the reverse of this is true in the case of abnormal negative pressure, that the greatest negative pressure seems to exist within the cavity of the ventricle itself. For this reason this could not satisfactorily account for the negative pressure, therefore, we have the second explanation.

2. This negative pressure arises, in all probability from the rapidity of the ventricular process of relaxation, representing the rapid return of the ventricle from its contracted to its normal condition. This will also account for the greater negative pressure that is found in the left ventricle because the thickness of the wall of the left ventricle is much greater than that of the right ventricle, and therefore the rapid contraction of the left ventricle will produce normally a greater negative pressure. This negative pressure assists the circulation of the blood by setting up a suction action which directs the blood that has been collected in the auricle into the ventricle, using up almost instantly the negative pressure and preventing it from exercising any disadvantageous influence upon the circulation. The only effect of this negative pressure is to lower, and practically to exhaust the negative pressure in the auricles without extending backward to the veins. In regard to the cardiac pressure in the ventricles we may conclude, therefore, that there are four different phases.

1. The rapid growth of pressure in the ventricles greatly increases until it becomes greater than the aortic pressure when the aortic valves are thrown open.

2. Following this the blood escapes into the aorta while the contraction of the ventricular walls still continues.

3. This continued contraction of the ventricular walls secures the complete emptying the cavities of the auricles.

4. The sudden relaxation of the ventricular wall, during which there is set up the negative pressure, this negative pressure establishing the connection between the ventricle and the auricle by which the blood is induced to pass from the auricle to the ventricle.

Duration of the Cardiac Movements.

The whole cardiac movement is termed a cardiac cycle and consists of three phases, the systole of the auricles, the systole of the ventricles and the pause or diastole of auricles and ventricles, which consists of thediastole of the ventricles, including the period between the cessation of contraction and the commencement of contraction again; and of the diastole of the whole heart, including the period from the end of the ventricular relaxation to the beginning of auricular contraction, during which the walls are neither contracting nor relaxing, the cavities being passively filled with blood. By using the instrument (cardiograph) in connection with the kymograph, the velocity of the surface on which the tracings are made can be estimated and thus approximation made to the time occupied by the cardiac movements. It is found that the systole of the auricles is very short, whereas that of the ventricles is much longer, occupying a considerable part of the cycle period and the diastole of the whole heart varies considerably, in slowly beating hearts being longer and in quick beating hearts shorter. From this we would conclude that the faster the heart beats, the briefer the diastole, and also the briefer the ventricular systole. The chief data used is that in connection with the first and second sounds. This period has been found to vary from .225 to .346 of a second, the variation being small, indicating that the variation takes place—in the pauses rather than in the actual beats. The first sound takes place along with the ventricular systole, and the second sound which marks the close of the ventricular systole. Thus the period between the commencement of the first sound and the second sound represents the ventricular systole. During this ventricular systole there takes place the increase of pressure, the expulsion of the blood and the continued so as to empty the cavity. The cardiac pulsations in the adult male vary from 65 to 75 per minute, in the new born child about 140. There is some relation between the quantity of blood in the circulation and the frequency of the pulsation. Thus as the pulsation becomes more frequent the quantity of blood which passes through the heart per minute increases. In the normal adult male the pulsation will be 72 in the morning, from 70 to 68 in the forenoon, 80 to 84 after meals, and 69 to 70 toward evening, the number of pulsations being fewer during sleep

Taking 72 as the normal heart beat, each period of revolution would occupy about .8 of a second. .3 of a second would represent the ventricular systole, the remaining .5 of a second would represent the ventricular diastole, during the latter part of which takes place the auricular systole representiag about .1 of a second, the .4 of a second representing the period during which neither auricle nor ventricle are contracting. One of the most important questions is the work done by the heart representing the quantity of blood ejected from the ventricles during each systole. It is estimated that 188 grams of

blood (a little over 6 ozs.) is driven out of the left ventricle into the aorta during each systole. Various methods have been used to discover this. The most simple is to remove the ventricle, fill it with blood, equal to the amount of blood calculated from the average pressure of the ventricle. This would give the quantity ejected, as the whole contents are driven out at each systole. Each ventricle gives out the same quantity at each beat, otherwise the blood would be crowded into the pulmonary or into the systemic circulation unequally. Some think this is not the case as the pressure is much greater in the left ventricle than in the right. This, however, is due not to the amount of blood but to the greater peripheral resistance to be overcome in the systemic circulation as compared with the pulmonary circulation. Taking 188 grams as the quantity ejected at each beat at the aortic pressure, which is estimated as 250 mm. of mercury, i. e. 3.2 metres of blood. This means that at each systole the ventricle does 601 gramme-metres of work every beat Taking the heart pulsation at 72 per minute we would have 42.272 kilogram metres for the left ventricle per minute or 60,872 kilogram-metres per day. The right ventricle would be about 2·5 of this amount or 24,349 kilogram-metres, the whole work of the heart in a day amounting to 85,221 kilog. metres or about 1-75 of 1 horse power, equal to the combustion of nearly 30 grams of carbon. If 188 grams of blood leave the ventricle at each beat a quantity equivalent to the whole volume of blood (about 5760 grams in a man of 75 kilograms) would pass through the heart every 30 beats, or once every 25 seconds.

These phenomena of the heart are more or less obvious upon observation. Beneath these are certain molecular changes on which depends the rhythm of the heart and by which many, if not all, of the vital activities are to be explained. One question arises as to the nature of the contraction. Is it a simple contraction, or is it a tetantic contraction? In other words is it due to the single stimulus or the application of a number of stimuli rapidly applied in close succession.

Many of the phenomena of cardiac contraction seem almost identical with those of a skeletal muscle. Exhaustion decreases the amount and increases the duration of the contraction. In cardiac contraction the period of latent stimulation is much longer than that of the skeletal muscle (proportion ⅓—1-100 of a second.) The length of cardiac contraction is greater than that of muscular tetantic contraction. The electric phenomena of cardiac contraction resembles a simple contraction, e. g. there is negative variation in connection with the heart and by the use of the rheoscope (for testing the electric current) the heart manifests a simple twitching. In the muscle when tested by electricity each contraction is preceded by a short period of lessened excitability representing molecular changes preceding contraction. This is known as the negative variation. By cutting off the ventricle slightly above the auriculo ventricular groove, Muller found that placing the base and the apex on the two galvanometer cushions—there was a negative variation in the heart. Later investigations proved that this negative variation took place in connection with the systole, the negative wave being transmitted at the rate of 20 mm per second. If the heart be rendered motionless by separating the auricles of the sinus venosus, either by ligature or by an incision, it has been found that the variation goes through two stages: (1) the initial stage, stage following immediately the excitation when the portion excited becomes negative to the other parts; (2) the terminal stage coincident with ventricular relaxation, the reverse of that manifested at the beginning at the ventricular systole. There is thus a two-fold negative variation manifested in the systole of an excised heart, the 1st at the apex and the 2nd at the base. The period of excitation does not correspond with the period of latent stimulation but coincides with the period from the beginning of the initial stage to the beginning of the terminal stage. The total period of the initial stage has been found to average about .12 of a second. The application of heat to the apex was found to have no effect upon the initial stage but to increase the terminal stage. The rate of transmission of the stage of excitation was found to be about 125mm per second. From this it is concluded that if the ventricle is stimulated, it becomes at once negative to all the other parts, the wave of stimulation being transmitted in all directions at the rate of 125mm per second. Immediately after this stimulation wave passes there follows a contraction of the fibres, giving rise to a wave of contraction passing over the heart. This wave of contraction in the mammalian heart is found to begin at the apex.

What is called a cardiac contraction commences near the orifices of the larger veins in the right and left auricles. In the case of a heart that contracts slowly, the wave of contraction originates at the orifices of the veins, enters the veins and passes along a short distance, then passes over the auricles and the ventricles. The question that arises here is, whether the cardiac movements are dependent upon molecular changes in the muscular tissue or in the nerve tissue, or in both It is a known fact that rhythmic movements take place in tissues that are not nervous, e. g., the beating organs of many invertebrates, the embryonic heart, the unstriped muscles of the ureter. In these cases there is a compound structure of muscle and nerve. Both muscular and nervous tissues, under definitite conditions, give rhythmic movements. It is, however, believed by many that the rhythm of muscular tissue takes its rise from the impulse of nervous tissue Several experimenters have found that the rhythm of the ventricles is altogether independent of the rhythm of the auricles, the ventricular rhythm being found in the apex where no nerve cells are found. This, however, while purely myogenic, is localized and may be overcome by the general rhythm of the heart as a whole. While connected the ventricular and auricular beat maintain almost uniform properties, whereas on the disconnection of auricle and ventricle, the auricle which keeps up the normal beat, beats faster than the ventricle. It is generally conceded that the rhythm of the auricle originates in the veins which transmit the rhythmic motion by muscular conductivity to the auricles. As the ventricles are structurally distinct from the auricles it is difficult to see how the muscular conduction can account for the propagation of the rhythm from the auricles to the ventricles. Hence, some Physiologists accept what seems the only alternative, that the contraction is transmitted from auricles to ventricles by nervous tissue. This, however, seems quite difficult to understand. These impulses could not be transmitted from auricle to ventricle so as to secure exact succession of ventricular beat after auricular beat without taking for granted the existence of nerve ganglia for the purpose of storing energy to be used at intervals in the ventricular movements. The connection of veins and auricles and the elasticity and rhythmic character of the auricular wall seems sufficient to account for the auricular transmission aside from the necessity of nerve centers.

Gaskell, by experiments on the apex of a frog's heart, which contains no ganglia, has shown that, (1) the involuntary apex beats depend upon the pressure in the cavity and not upon the blood supply; (2) that by the addition of a weak alkali to the blood supply of the apex relaxation gives place to contraction and a weak lactic acid solution reduces the apex to a perfect diastole, Muscarin producing almost the same result. Gaskell draws some interesting conclusions from these experiments. (1) Independent rhythmic contraction is lessened as we pass from the sinus to the ventricle, the power of such rhythmical contraction varying inversely with the distance of the part from the sinus. (2.) An excised part of the apex can be made to beat artificially at the same rate as the sinus and auricle by the action of nutriment. (3.) A wave of contraction transmitted by the auricle produces ventricular contraction, after passing the auriculo ventricular groove. (4.) By dividing the auricle so as to leave one part in connection with the sinus and the other in connection with the ventricle, a contraction wave passes up the strip extending from the sinus to the bridge, passes over and then after a brief pause goes down the part from the bridge to the ventricle and into the ventricle, resulting in contraction. By diminishing the extent of the bridge, then only every second contraction passes over, resulting in ventricular contraction, no response being made in the case of the wave stopped. If this bridge is made very small then there is no passage of contraction between auricle and ventricle and the ventricular contractions are entirely independent of the auricular. The nervous action according to Gaskell, in the case of nerves passing from auricle to ventricle, conveys impulses from the ventricle to the heart, regulating the blood supply, increasing the conductive power of the auricle substance. He suggests that the influence of the vagus is to assist and render more efficient functional activity being the trophic nerve of the heart; upon its relation to the heart depending the character of the heart functions and their intensity as these functions are discharged by the cardiac muscle. In the cardiac muscle, which differs from the striated and unstriated muscle, the rhythmic activity is most perfectly developed. Hence he concludes, that the apparently opposite actions of the sympathetic and the vagus—upon the heart depends upon their connection with the process of heart nutrition.

The vagus exerts an anabolic influence, leading to and directing the processes of repair in the heart substance, while the sympathetic exerts a katabolic influence, directing the processes of decomposition by which the complex muscles are divided into simpler bodied. These represent the molecular changes taking place in connection with the cardiac muscle, the nervous influence being rather of a trophic nature. According to this idea, the rhythmic contraction of cardiac muscle is its special characteristic. This rhythmic tendency is found most fully developed towards the base in the tissues around the orifices by the large veins and in the auricle. This rhythm, originated in the region of the venous openings is transmitted through the auricles to the auriculo-ventricular groove; the rhythmic contraction of the ventricular tissue being produced by the electric variation arising from the rhythmic auricular, assisted by the increased cardiac pressure arising from the blood flow from auricle to ventricle. In the human heart these trophic influences are aided by the intra-cardiac ganglia, these in turn being influenced by the extra cardiac nerves. These nervous influences, however, are not the producers of the energy which manifests itself in cardiac contraction, but exercise an influence upon the cardiac pressure, and indirectly in this way govern the heart's action by securing the normal contraction of the walls of the heart cavities, and influencing the nutritive changes taking place in the muscle substance of the heart. In this way the ultimate solution of the cardiac rhythm depends upon the trophic influence of the nervous system upon the cardiac muscles.

Persistency of Cardiac Movement.

The heart continues to beat after it has been removed from the body. This movement continues longer in cold blooded animals, as the frog, than in warm blood animals. The heart of the frog will continue to beat for two or three days; a rabbit's heart from three to seventy-two minutes; in the case of the right auricle, which is the ultimum moriens. The last trace of beating has been found in the rabbit 15 hours, and in the dog 96 hours after death, and in the human embryo the heart has been found to pulsate for four hours after death.

After the cessation of the heart beat stimulation may cause contraction. The ventricular contraction weakens first, then the contraction of the auricle is not followed by contraction of the ventricle, the ventricles contracting slowly, then ceasing to contract while the auricles continue to contract. Finally the right auricle ceases to contract. Even after stimulation fails to produce any contraction in the case of the heart by the injection of arterial blood into the coronary arteries the heart may be restored to pulsation.

Cardio-Pneumatic Movement.

During systole the heart occupies a smaller space in the chest cavity than during diastole. It follows from this that if the glottis be open, air will be drawn into the lungs when the heart contracts, whereas when the heart relaxes, air is expelled through the open glottis. Of course, account must be taken of the amount of blood in the larger vessels of the thoracic cavity. This circumstance seems of value in hybernating animals, as the movements of the lungs assist the exchange of oxygen and carbon dioxide, a sufficient air current being produced to aerate the blood as it passes through the lungs. Landois invented a cardio-pneumograph for the purpose of tracing these movements. It consists of a tube about one inch in diameter and six or seven inches in length. This tube consists of two parts, one for insertion into the mouth on the side of which is a valve to regulate the breathing and another part at right angles to the part inserted in the mouth attached to a metal capsule covered over with membrane. Attached to the membrane is a glass rod used as a stylus, which records the movements upon a recording glass plate. When the tube is placed in the mouth, the nostrils are closed the glottis is open and respiration ceases. From the tracings we can see (1) an expiratory movement at the moment of the first sound, because the blood is pouring into the right auricle through the venae cavæ and the dilating branches of the pulmonary artery compress the bronchi, the blood of the right ventricle passing into the pulmonary circulation. (2) A strong inspiratory movement follows, because more blood passes out of the chest than enters it through the vena cavæ. (3) After the semilunar valves have closed, arterial blood accumulates in the chest and hence, another expiratory movement follows. (4) the blood rapidly passes from the arteries in the chest outside of the chest and there follows an inspiratory movement of the air in the lungs. (5) then follows the flow of blood into the heart through the veins, followed by the heart beat.

Influence of Respiration Upon Cardiac Action.

The thoracic cavity contains within it, as an air tight compartment, the heart and the lungs. As the chest increases or decreases in size during inspiration and expiration, a certain amount of pressure is exerted upon the heart and influences, to some extent, its movements. During inspiration the diaphragm descends and the ribs are raised while the lungs expand, thus increasing the chest cavity. The pressure upon the external surface is less, the heart being in a condition of diastolic dilatation. During inspiration also the pressure is removed from the large veins entering the chest at the right side of the heart, and the flow of venous blood toward the heart is assisted. If after a very deep expiration the glottis is closed so as to prevent the admission of fresh air to the lungs, and if the chest be then distended by a very strong inspiration, the heart becomes dilated, this dilatation being increased by the

elastic drawing of the lungs. The venous blood flows into the right side of the heart, the blood is sent on to the lungs and thus the lungs become gorged while the left side of the heart cannot drive out sufficient blood into the arterial system. The pulse may disappear, the heart being distended and the lungs congested, while the arterial system contains but little blood. This is called Muller's experiment. During expiration the pressure on the external surface of the heart is increased and also on the external surface of the large veins, while only a small quantity of blood flows into the heart at its right side, the heart being contracted and the pulse beat small. In the Valsalva's experiment this is is increased. A very deep inspiration is taken and then the glottis is closed. Immediately a powerful expiration is made. contracting the cavities of the chest and heart so as temporarily to interfere with the blood circulation. The air in the lungs is under high pressure and it acts strongly upon the heart and thoracic cavity. Hence the veins in the face and neck become swollen, the blood from the lungs is quickly forced into the left ventricle, passing it into arterial circulation. The heart and lungs in this condition have little blood while systemic circulation there is a large quantity of blood. The heart sounds cease and the pulse disappears, indicating syncope. These represent abnormal conditions. In normal inspiration the air in the lungs is under slight pressure favoring the flow of blood into the heart and diastolic dilatation; whereas, in expiration the pressure is higher, favoring the flow of blood out of the heart into the aorta and thus aiding the systolic empting of the heart.

Cardiac Sounds.

When the ear is applied over the chest, either by the ear itself simply, or by the use of the stethoscope, two sounds are heard, one directly from the apex. This is a dull, long and booming sound. The second sound that is heard from the base, is shorter, sharper, more sudden and more clear. The first sound is heard during the apex beat and corresponds with the ventricular systole; hence, called the systolic sound. The second sound follows the first after an almost inappreciable period of pause, and it corresponds with the first part of the diastole of the ventricle. Following the second sound, there is a period of rest, or the long pause, as it is called, lasting till the commencement of the first sound in the next succeeding ventricular beat. This period of rest, therefore, corresponds with the latter period of the ventricular diastole, and also, with the systole of the auricles. These two sounds differ in their character. The first as we said, is low and presents a muffled sound, while the second sound is high and distinct. A difference is noticeable when the sounds are heard over the apex and over the base. Over the apex the first sound is accentuated, while over the base the second sound is accentuated. These sounds are usually represented by the meaningless words, "lupp dupp, pause, lupp dupp, pause, representing the characteristics of the sounds. The duration of thsee sounds depends to a large extent upon the listener, that is, it is subjective rather than objective. Walshe has stated that in the cardiac cycle taking the base of ten in the cardiac cycle, the first sound occupies 4 parts of the 10, then the short pause occupies 1 part; after the short pause, of course, we have the second sound, which occupies two parts, and the 3d sound three parts.

Much difference of opinion exists as to the cause of the first sound; this first sound may be heard distinctly after the removal of the chest wall, indicating that the heart beat does not produce this sound. Some Physiologists ascribe this sound to vibrations in connection with the close of the mitral and tricuspid valves. Others regard it as due to the muscular contraction of the tissue in the ventricles. Others say that it is due to the flow of the blood through the aortic and pulmonary openings. The most probable cause, however, is what is called the double arrangement, consisting of the first and second, the valvular element and the muscular element.

This 1st sound is not a short, sharp one, such as we would expect in the case of the sound produced by the vibration of the valvular membranes, neither does it seem possible that this long and dull sound could be produced simply by the flow of the blood. One thing is certain—that is, that in the nature of this sound, a muscular sound, differing in its quality from the normal muscular sound on account of the pecularity of the cardiac substance. Prevailingly this sound is muscular, and in all probability, modulated and modified by the vibratory action of the auriculo-ventricular valves. In the case of the still living excised heart, the first sound has been heard quite distinctly. For example: The heart of a dog was first loosely and then tightly ligatured in the venae cavae, the pulmonary artery and veins and the aorta. After the ligatures were made as tight as possible, the heart of the dog was excised and placed in the glass vessel and filled with defibrinated blood. In the experiment, the narrow bottom of the conical glass was closed, not with glass, but with artificial membrane, and this membrane was connected by means of a flexible tube with a stethoscope. On listening through the stethoscope the second sound was not heard at all, whereas, the first one was heard very distinctly at each contraction of the ventricle. In this case the heart was empty of blood so that the closure of the valves could not possibly produce this first sound. In addition to this, we have the fact that in abnormal conditions when the muscular walls of the heart are weakened. For example: in an advanced case of typhus fever, the first sound may disappear entirely. On the other hand, in the case of diseases of the mitral valves a sound may be heard quite distinctly, of a blowing nature. This blowing sound, in some cases, may hide and in other cases, it may change altogether the character of the first sound into that second blowing murmur. The reason being that the sound, blowing sound, becomes so strong that it seems to over-bear the other sound and prevent, not the sound itself, but the communication of the sound. From this we conclude that the valves in their vibrations, give rise to a sound which becomes blended with the muscular sound produced by the heart substance and resulting in what we call the normal first sound of the heart. Wintrich, a German physician who has investigated this subject, by the use of the stethoscope combined with a resonator, has been able to detect in the first sound two elements, one part or element, on a high pitch, which he ascribed to the vibration of the auriculo-ventricular valves, and another part on the low pitch, due to the muscular cardiac contraction.

The second sound has been known very distinctly in its character since the time of the Physiologist Laennec. This sound, according to Laennec, was due to the sudden vibrations caused by the sharp closure of the sigmoid valves, when the diastole of the heart has just commenced. This sound is best heard over the 2d left costal cartilage close to its junction with the sternum. It is at the point where the aortic arch approaches close to the surface and hence, transmits conveniently the sound to the surface. Williams, one of the Physiologists, found that this second sound could be heard by applying the stethoscope directly to the heart. By passing a curved wire through the pulmonary artery the semilunar valve was hooked up. The aortic semilunar valve was similarly hooked up. In this condition the second sound had disappeared altogether and could not be heard. On withdrawing these obstructions the hissing murmur which existed while the valves were suspended had given place to the second normal sound. As we said before, the aortic and pulmonary valves do

not close simultaneously, they have a brief, a very brief, interval of time between their closure. If this interval be lengthened, we have what is called the reduplicated second sound—that is, the double second sound—one sound arising from the aortic and the other sound from the pulmonary artery.

During the first sound we find the following phenomena: (1) Ventricular contraction, (2) closure of the tricuspid and the mitral valves, (3) the flow of blood into the aortic and pulmonary arteries, (4) the heart beat, (5) the auricles filling with blood. During the second sound we find the following phenomena: (1) The closure of the semilunar valves, (2) relaxation of the walls of the ventricles, (3) opening of the tricuspid and mitral valves so as to admit the passage of the blood from the auricles to the ventricles, (4) diminution of apex pressure against the chest wall. During the long pause which is marked by the three tenth portion of the cycle we have (1) the auricle being filled with blood by the passage of blood from the ventricle, (2) auricular contraction, expelling all the blood out of the auricle into the ventricle. The short pause the one occupying the 1-10 period, the time is almost inappreciable and it may be said to represent the maximum of contraction in the case of the ventricle.

SECTION V.—The Heart in Isolation.

It is important to study the heart in isolation, because there are so many phenomena of importance in connection with the isolated heart. Many methods have been invented to study the heart movements in this isolation. The crudest method is to place the frog under the influence of curare, then placing it on its back on a cork plate to which is adjusted a fine lever that can be placed over the beating heart after the removal of the anterior wall of the thorax. In this way the movements of the beating heart communicate the impulse to the moving stylus attached to the lever which will record its tracing on the kymograph. If the heart excised from the frog is placed on a copper plate and over the heart a lever attachment be placed, it will be found by heating the plate that the heart beats more quickly, as the heating process increases until it passes into the tetantic state due to the thermal stimulation.

This tetenus will pass away on cooling the plate with ice. By the use of Marey's cardiac forceps the heart's movements can be noticed very distinctly. The frog is placed upon a plate so that two small cups can be placed over each side of the heart, each cup is connected with a horizontal bar over the top by means of two vertical arms, the one arm fixed and the other arm movable, the movable arm bearing a very small horizontal lever. At each systole of the heart the forceps will open and the lever will move and this movement will pass through the movable arm to the horizontal bar, this movement being communicated to a recording instrument.

Roy, another, Physiologist, has invented an ingenious instrument which he calls a tonometor for the purpose of studying those influences that act upon the beating heart under isolation. This instrument consists of a bell jar whose rim rests easily upon a greased groove in the brass plate. Through the jar stopper there passes a perfusion cannula to which the heart is attached so that the blood may continue to flow through the heart. At the center of this brass rod there is an opening through which an aluminum piston works. Around the edge of the lower end a fine membrane is stretched loosely. The middle of the membrane is connected to the upper surface of the piston, so that when the piston moves the membrane moves with it. The piston is connected with a fine rod to which a lever is attached underneath. The vessel is filled with olive oil and the heart is suspended in this fluid.

During diastole the heart expands, pressing down the piston rod and the point of the lever is connected with the recording kymograph. When the systole takes place the piston again rises, giving us tracings which are very characteristic of the heart's movements. In this way we have the tracings of the diastole and systole of the heart in isolation.

Nutrition of the Heart.

The heart is nourished by means of nutrient fluid carried to the different parts of the heart through the circulation. In the lower vertebrates this is secured, for example, in the frog, by passages going out irregularly from the heart cavities through the midst of the heart muscle close to the peripheral surfaces. These passages act as blood vessels, filling at each diastole and emptying at each systole, and, of course, conveying the blood to the cardiac muscle. In the rabbit, the cat, and the dog, and especially in man, heart nutrition takes place by means of the well developed cardiac circulation, the cardiac circulation being carried on through the coronary arteries and veins. In the case of the dog the coronary arteries and their branches are very close to the heart surface, the pericardium furnishing their covering. The left coronary artery originates at the aortic orifice, dividing into two branches, called the circumflex, and the desendens branches. The circumflex branch passes transversely outwards in the left auriculo-ventricular furrow, passing around the left side of the heart to the posterior surface and supplying with blood the left auricle and the upper anterior and posterior parts of the left ventricle. The desendens branch runs down the anterior inter-ventricular furrow to the apex of the heart giving out a number of branches to the left ventricle and to the anterior portion of the septum ; supplying with blood the septum and the inferior anterior portion of the left ventricle. The right coronary artery arises from the aorta just above the free margin of the anterior semilunar valve, passing to the right auriculo-ventricular furrow or groove around the right side of the heart, running as far as the posterior inter-ventricular furrow, where it divides into two branches. The right coronary artery supplies the right auricle and the right ventricle with blood. The small branches of the coronary arteries enter into the cardiac substance ending in the capillary plexus which carries the blood to the heart substance. Out of these roots originate the cardiac veins which carry the venous blood to the right auricle by means of the anterior cardiac veins and also the smaller veins, the foramina Thebesu.

Before entering the auricle, the large coronary vein becomes dilated, forming what is called the coronary sinus. At the junction of the vein with the sinus there is a valve, the other coronary veins which enter this large coronary sinus also have valves. The coronary arteries are terminal, at least, in man, that is, the anastomosis of the arteries does not produce a collateral circulation. This terminal character of the coronary arteries is of the greatest importance in connection with heart nutriment. The rapid closure of one of the large coronary branches in the case of the dog, for example, has been found to have little effect, some say, no effect at all, on the heart's action; others say it has a temporary affect, in producing an irregular action of the heart, or after a few seconds it may effect the ventricular action, producing what are called fibrillary movements. There fibrillary movements result from the shortening of the cells found in the cardiac substance. This arrest of ventricular activity depends upon the heart irritibility, and also upon the size of the vessel that is ligatured. When the force is sufficient and produces these effects, the ventricular pressure is lowered during systole and increased during diastole, resulting, of course, in diminishing the force of the ventricular contraction and also the ventricular

belaxation, sometime resulting in the cessation, altogether, of the ventricular hreat. Some physiologists have explained these changes upon the basis of anæmia—the scarcity of blood; others claim that these changes result from an injury to the muscles and also an injury to the nerves taking place during the process of ligature. In the latter case it is claimed that anæmia alone does not cause the fibrillary movements, whereas mechanical injury from the process of ligature does cause the stoppage of heart action. These statements however seem to lack confirmation by experiment.

The anæmic condition may produce these results. This can be shown by slowly interrupting the coronary circulation by the withdrawal of blood, in which case we find feeble inco-ordinated contractions. In this case the stoppage of the blood supply is slow, whereas, in the case of ligature the blood supply is suddenly cut off from the heart muscle. Some recent experiments have shown that even after such fibrillary contractions the normal movements of the heart may be again restored by establishing the artificial cardiac circulation, indicating the fact that these fibrillary contractions are only temporary. In the case of the valves entering the coronary sinus there seem to be two special functions discharged by these valves.

1st Function, intercepting the blood current during the systole of the right auricle, preventing regurgitation and the congestive condition of the walls of the heart.

2d Function, by the opening of these valves toward the auricle they prevent the backward flow of the blood during ventricular systole and aid the accelerated flow of the blood. It is during the ventricular systole that the blood enters the cardiac circulation and but for these valves the cardiac circulation could not take place normally.

The coronary arteries arise, as we said before, at the aortic opening near to the sinus of valsalva, and as sinuses always receive sufficient blood to supply to the arteries, they can easily receive a sufficient blood supply during the ventricular systole.

In order to complete the nutritive process, the heart has its lymphatic system very fully developed underneath the pericardium and the endocardium and also, throughout the entire muscular substance. These lymphatics originate among the muscular fibres, the inter-spaces between the muscular fibers being lined with endothelium cells. Between the aorta and the trachea there lie lymphatic glands ascending along the trachea and terminating in the duct along the course of which the lymph is carried from the heart to the thoracic duct and also to the right innominate vein.

SECTION VI.—The Innervation of the Heart.

The nervous mechanism of the heart is most important and has been very fully investigated, because of the influence which the nerve centres exert upon the heart and the heart's action and also because of the questions which arise in regard to the relation of muscular action and nervous action in connection with the heart beat. The nervous mechanism has a double bearing. 1st, upon the heart as the center of the entire vascular mechanism, and 2nd, upon the changes that take place outside of the heart, especially in connection with the minute vessels. The heart really regulates and brings together the varying activities of the different parts of the body, while in turn, the heart is regulated by the nervous system. It is by means of the nervous system that a fuller supply of blood exists during work than during rest, and especially the work of the heart is so moderated as to meet and overcome the constant strain upon the heart substance.

It has been known for a long time that the heart of the frog can be kept beating after its entire removal from the body for many hours—normal beating, we mean—and even after the cavities are entirely empty of blood. This has been accomplished in the case of the heart of the dog and cat and the rabbit, indicating this fact, that the cause of the rhythmic heart beat must be somehow in the heart itself and not in its connection with the central nervous system. We have already discussed the causes producing this cardiac movement and we have found that it is due to the muscular contraction, a muscular contraction kept sustained by the impulses found either stored in the ganglia or communicated by the nerve fibres. This muscular contraction then is dependent upon the trophic influence of the nervous system. The heart beat, therefore, the normal action of the cardiac substance and the nutrition of the heart substance depends upon the nervous system and hence shows the importance of the careful study of the innervation of the heart. The view has been maintained that as the pulsations cease—that is of the heart—under ordinary circumstances in the following order: the lower part of the ventricle toward the apex, the entire ventricle, the auricles and then the sinus venosus, and as these parts in an inverse order represent a series of ganglia, much more numerousin sinus venosus, and altogether absent in the lower ventricle; therefore, it is concluded that the rhythmic heart beat depends upon the nervous impulses originating in these ganglionic nerve cells, passing down different fibres to the different parts of the heart, causing the rhythmic fiber contraction, which cordinate by the co-operation of the different ganglia. This would make the muscular fiber passive in the hands of the ganglia centers, but as we have seen this is not the case. The strongest impulse in contraction being muscular, this being sustained by the trophic influence of the nervous system. In the innervation of the heart we have to consider: (1) the extrinsic or extra-cardiac nervous mechanism, including the nerve centers and the great nerves connecting the heart with the central nervous system; and (2) the intrinsic or intra-cardiac nervous mechanism, including the nervous arrangement of the heart.

EXTRINSIC NERVOUS MECHANISM.

This mechanism consists of nerves branching off from the cerebro-spinal and sympathetic systems so that the cardiac nerves are branches of the vagus and sympathetic, arising in the region of the inferior cervical ganglion. These nerves form two groups, one internal and one external. The internal group comprises a medium sized nerve, springing from the inferior cervical ganglion, a thick nerve springing from the trunk of the vagus near to the origin of the inferior laryngeal nerve and several fine nerves which arise from the vagus terminating in the cervical plexuses. The external group consists of an upper nerve originating in the inferior cervical ganglion or in the vagus trunk close to the inferior cervical ganglion, and a lower nerve arising in the lower curve of the annulus of Vieussens or sometimes, from the vagus close to the annulus.

In the year 1845, the Weber brothers discovered that the stimulation of the vagus trunk in the neck or at its deep origin in the grey matter on the floor of the fourth ventricle, produces in the case of a feeble excitation a lessening of the number of the heart-beats and in the case of a strong excitation it produces the entire arrest of the heart's action. This arrest of the heart's action taking place in diastole and by a gradual filling of the heart with blood. Having found that the inhibitory power resided in the medulla, the question then arose "how was this impulse transmitted to the heart?" By a section of the pneumogastric it was found that the action of the heart was accelerated, while on stimulating the cut end of the peripheral portion, the heart's action was slowed, and in some cases completely suspended. The influence of the pneumogastric fibers, therefore, on the heart is inhibitory or restraining. From this experiment we conclude the action of the vagus upon the heart is inhibitory or restraining. The slowing and arresting of the heart's action may be produced by different kinds of stimulation; for example: chemical stimulation, or mechanical, as well as electrical stimulation. One Physiologist has discovered that the pressure of the carotid artery at the anterior margin of the sterno mastoid would result in slowing of the action of the heart which he supposed to be produced by the stimulation of the pneumogastric. During this arrest of the heart, the heart does not cease to be subject to irritation, for during this inhibitory action it will still respond to stimulation. This arrest of the heart action is not due to reflex action, but is direct, because this arrest will take place on excitation or stimulation of the peripheral end of the cut nerve. This inhibition is not constant.

The right vagus seems to have a greater influence on the heart than the left vagus, and it is found, on excitation of the vagus, the auricles of the heart in particular are affected—that is, the part of the heart affected by stimulation of the vagus, is the auricle. This influence of the vagus affects, not only, the frequency of the heart's pulsations, but also, the strength or the force of these pulsations. This is evident from the fact that on the stimulation of the vagus, the pulsations become fewer in number and, also, each pulsation becomes more feeble. This stimulation of the vagus may be increased by the section of the spinal cord, and also of the sympathetic in the upper portion of the neck. This excitation of the vagns affects the periodicity of the ventricular action, particularly the ventricular systole; the feeble stimulation of the vagus greatly increasing the period of diastole, and also the diastolic pressure. A strong stimulation increasing, on the other hand, both the periods of the systole and diastole. Even in the case of the continued stimulation, however, the heart after several seconds begins to beat, at first very feebly, and then after a short period resumes its normal beating without removing the stimulation. The effect of this stimulation is to lessen the force of the ventricular contraction, increasing the quantity of blood at the close of the systole, and at the close of the diastole of the ventricle, diminishing both the amount of blood that is received and given out. The tone of the ventricle is also affected by this stimulation, being slightly diminished. The proof of this is found in the fact that the walls of the empty ventricle after stimulation, are found to be soft and flaccid, giving up, to a certain extent, the strength that is found normally in ventricular walls, due to the thickness, particularly of the one ventricular wall. In the case of the auricle, the excitation of the vagus, diminishes the force of its contraction, lengthening the diastole, these changes appearing earlier than the changes that are found in the ventricles, indicating what we do find, that the ventricle is affected through the auricle. In the case of strong stimulation of the vagus the heart does not contract at all, or at least with less vigor. A single electrical stimulation will not arrest the heart action at first, but if the stimulation be continued, it will affect the heart, different parts of the heart with varying intensity. Weak stimulation for example, affects the auricle and then indirectly through the auricle it affects the ventricle. Strong stimulation, on the other hand, stops the action of the auricle while the ventricle remains for a short period, unarrested and then stops. Very strong stimulation inhibits, not only the auricle, but also, the ventricle. It would seem from what we have seen, that the vagi, the right and left vagi, do not act directly upon the fibers of the heart, but rather upon the intrinsic nervous ganglia, although in what way this action takes place, we do not know.

It is probable, however, that the same intra-cardiac terminal acts for the two vagi, for when one vagus is stimulated till the heart overcomes the effect of stimulation the excitation or stimulation of the other vagus has no effect upon the heart at all. Gaskell, who has devoted much time and attention to this subject, accounts for the medium of the inhibition by the fact that the vagus is the trophic nerve of the heart. He thinks that after the stimulation is over, the heart becomes more vigorous, this being according to Gaskell the proof that the excitation of the heart through the stimulation of the vagus has nourished and made it stronger than it was before and, therfore, is considered to act more vigorously. As yet, however the experiments have not sufficiently established this point, although it seems very probable.

Bezolo discovered that after a section of the spinal cord between the first and second thoracic vertebrae the stimulation of the cervical cord produces an acceleration of the heart's action. This stimulation he found was carried or conveyed from the cord to the inferior cervical ganglion, from which center it passed through the nerve fibres to the heart. These accelerator fibres enter the sympathetic from the spinal cord, coming from the inferior cervical and the first thoracic ganglia, dividing so as to form the annulus of Vieussens and then joining the vagus trunk From the superior cervical ganglion fibres pass into the vagus, passing down the trunk into the cardiac plexus between the superior and inferior laryngeal nerves. The spinal nerves, from the 1st to the 11th and possibly to the 12th, send out fibres to the superior cervical ganglia, the sympathetic trunk and the first thoracic ganglion. This sympathetic acts as an accelerator, the section of the sympathetic even on one side being followed by the slowing of the heart's action, the heart being left to the action of the pneumogastric. If the cut end of the distal portion of the nerve be stimulated the heart will beat more quickly. The excitation also, of the fine fibres that pass into the heart from the inferior cervical ganglion accelerates the action of the heart or beat. These delicate fibres originate in the spinal cord for by separating the heart from the cerebro spinal system and leaving the sympathetic fibres the stimulation of the higher part of the spinal cord also causes acceleration of the heart beat. The chief result of the stimulation is the increase in the heart pulsations, that increase being according to some Physiologists, from 10 to 70 per cent of an increase The force of the ventricular pulsation increases. The ventricle becomes filled more completely with blood and the quantity of blood that is ejected from the ventricle is also increased. The stimulation of the nerves on both sides of the heart does not increase the heart action more than the stimulation of the one.

Auricular contractions also increase in strength and in volume, this latter increase in volume depending upon the increased elasticity of the relaxed auricle. These changes, accelerator changes, give rise to an increased blood pressure in the systemic circulation of the arteries and to a fall of blood pressure in the pulmonary veins and venous circulation to the heart. If the vagi, the inhibitory nerves, are stimulated at the same time as the sympathetic; the auricular and the inhibitory or the vagi action will overbear the action of the sympathetic, indicating that inhibition is stronger than acceleration. Even if the stimulation of the sympathetic is continued for a long time, and even if the stimulation is very strong and severe, the heart will not pass into a state of tetanus, but after quickening its pace for a short period it will return to its normal rate. This indicates that the accelerator fibres or nerves are not motor nerves of the heart. The sympathetic nerves fibres do not act directly on the heart muscle, but rather on the intra-cardiac ganglia causing them to give out their entire reserve stock of energy. When this stock of energy is exhausted

the stimulation of the sympathetic will fail to accelerate the heart's action. This seems to indicate one line of proof in the direction of Gaskell's idea that the vagi nerves act as trophic nerves by which the heart is nourished. The nerves are not irritable, hence Gaskell says we should not use the word irritable at all in connection with the vagi—we should use the word stimulation.

In the trunk of the vago-sympathetic and from the loop of the annulus of Vieussens certain fibres originate and pass to the heart which are not properly either inhibitory or accelerator nerves. For example, it has been observed that if the intra cardiac vagus act so strongly as to arrest the action of the auricles, excitation of the vago-sympathetic trunk will result in a marked increase in ventricular and auricular activity. This usually followed by an increase of the heart's action or beat. These changes are not purely inhibitory. Pawlow has classified the inhibitory and the accelerator nerves under four heads. 1. Those which inhibit the heart beat. 2. Those which inhibit the force of contraction. 3. Those that increase the heart-beat, and 4. Those which increase the force of contraction. Thus we have the inhibitory and accelerator force with two subdivisions of each. For example: It was found that in certain stages of poisoning by convallaria majalis that the stimulation of the vagus at the neck when all its branches were severed except those going to the heart and lungs were divided, that the blood pressure was lessened without affecting the heart beat. The stimulation of different branches from the annulus of Vieussens leading to the heart was found to produce in some cases a diminished blood pressure, and in cases of other branches a reduced heart beat, and in others an increased blood pressure independent of any other results. This seems to lead to the conclusion that certain nerves act upon the heart rhythm and others upon the contraction force forming the basis of the sub-division of Pawlow already mentioned.

The Reflex Action of Some Sympathetic Fibers and of the Cerebro Spinal Nerves.

In the sympathetic there are fibers which excite reflex action through the vagi. If the sympathetic nerve is divided at the neck and the cephalic portion of the nerve is stimulated, the heart's action becomes slow. This is explained by the fact that certain fibers of the sympathetic communicate through a center or centers with the vagus. Stimulation of these fibers arouse the activity of the center, and this activity is communicated by the center to the vagus. The cardiac ganglia, in this case, being inhibited and hence, the action of the heart is slowed. This will not take place if the vagi have been previously divided, or cut.

Gotz, one of the German Physiologists, has proved this by several experiments in connection with the frog. The chest-wall was cut by him, in such a way, as to expose the pericardium, through which the heart pulsations could be easily observed. By beating upon the abdomen with the end of the scalpel, the heart was gradually slowed, and finally the heart ceased to beat altogether. On stopping the beating on the abdomen, the heart rested for a short time and then began to beat more quickly than in its normal condition. Thus the fibers of the sympathetic in the abdomen, on being artificially stimulated—in this case it was mechanical stimulation—produce a reflex inhibition of the heart through the vagi. The stimulation of the central end of the splanchnic is found, also, to produce reflexly a rising blood pressure and the slowing of the heart's action. According to some Physiologists, splanchnic stimulation produces not a simple but a compound result; the stimulation resulting in increase due to the acceleration and inhibition toward the close of the stimulation. It has been found that a severe blow on the epigastrium or the sudden swallowing of a large quantity of ice-water produces syncope of the heart The dilatation of the stomach has been found to produce an inhibition of the heart. The stimulation of the sensory nerves seems to affect both the accelerator and inhibitory fibers. In the case of a weak stimulation the accelerator influence prevails and in the case of a strong stimulation the inhibitory influence prevails. The stimulation of the nerves of the special senses, sometimes increases and sometimes diminishes the action of the heart.

The strong irritation of the suborbital nerve has been found to arrest the action of the heart in diastole. The stimulation of the central end of the cut vagus causes, at least, a slowing of the heart beat, some say its complete arrest. If the vagus, on the other side, be cut, this slowing will disappear altogether, indicating that the stimulation of the central end of the one affects the heart through the other vagus—that is, it is a reflex action. At the same time the blood pressure is affected; sometimes it is lessened and sometimes it is increased, the difference in this case being due to the vagus which seems to differ in different individuals.

Depressor Nerve.—This nerve is sometimes called after the names of the parties who discovered it, Ludwig and Cyon. These two Physiologists finding that the stimulation of the nerves passing from the central nervous system to the heart aside from and independent of the vagus produced no effect upon the heart rate or the blood pressure, thought that this was due to the fact that the excitation was limited to the end of the divided nerve still in connection with the heart. They thought that stimulation of the end connected with the brain would produce, not negative, but positive results. In their investigations in connection with these nerves in the rabbit, they found an afferent nerve springing from the vagus, high up in the neck, the stimulation of its central end, producing a fall in the blood pressure. On account of its action, they called it the depressor nerve. This depressor nerve arises from two or more nerve roots, one of which springs from the vagus, and another from one of the vagi branches of the superior laryngeal nerve. If this nerve is single in its origin as it is sometimes, its origin is found in connection with the laryngeal nerve. Side by side, with the cervical sympathetic, it runs down to the chest where it communicates with the ganglion stellatum by some of its branches; the depressor fibers terminating in the ventricular walls of the heart. In the case of the dog, it is joined to the vagus and does not form an independent nerve. The depressor nerve is exclusively an afferent nerve. After it is divided on the stimulation of the peripheral end no effect is noticed in the heart rate, or the blood pressure. From this we conclude that the heart terminals in this nerve are quite distinct from the endings of the inhibition nerves or vagi, and also, independent of the ending of the accelerator nerves of the sympathetic. If the central end of the cut depressor is stimulated, a gradual fall of blood pressure follows, and at the same time there is a gradual diminution of the heart rate. On withdrawing this stimulation the blood pressure is restored to its normal condition.

If both the vagi are cut the excitation of the depressor nerve causes no change in the rate of the heart, but there is a fall of the blood pressure. From this we conclude, (1) that the change of the heart rate is produced by the stimulation of the cardio inhibitory center, the vagi acting as the medium through which the action affects the heart, and (2) we conclude that the change of the blood pressure does not depend upon the vagus remaining perfect or intact, for on the section of the vagi the pressure of the heart or the blood still continues to fall. By transmitting an impulse to the cardio-inhibitory center, the center is inhibited and its activity being restrained the small arteries dilate

and as a result there is a fall in the blood pressure. Normally, this center, that is, the cardio-inhibitory center is engaged in transmitting impressions which keep the muscular fibres of the arteries in a tonic state of contraction. This action being inhibited, the fall of blood pressure results on account of the lessening of the peripheral resistance. Poisoning by curare does not seem to affect the depressor nerves. There are two possible causes of the fall of the blood pressure. 1st, the cause may possibly be in the heart itself. This, however cannot be the case, because after all the nerves to the heart have been divided, depressor stimulation still continues to lower the blood pressure. (2) therefore, we are left to the other conclusion that the cause must lie in the arteries. By dividing the splanchnic nerve it was found that the abdominal arteries were dilated and the blood pressure fell. Excitation of the peripheral end of this divided splanchnic nerve on the other hand caused a rise in the blood pressure, whereas the stimulation of the central end did not produce any affect upon the rhythm of the heart or upon the blood pressure. This led these experimenters to conclude that the depressor nerve causes a fall of the blood pressure by lessening the tonic constriction of these arteries under the influence of the splanchnic nerve, resulting in arterial dilatation and the lessening of peripheral resistance. The depressor fibres connect the heart with the vaso-motor center, these fibres connecting with the vaso-motor center being stimulated when the heart becomes overfilled with blood, this stimulation passing through the fibers and the vaso-motor center and affecting the arteries under the splanchnic nerve, lessening the resistance and thus aiding the overfilled heart in emptying itself again. Thus the function of the depressor nerve is temporary, not continuous. This is evident from the fact that the section of the depressor nerve does not alter the blood pressure at all.

Some recent investigations have shown that the excitation of the depressor nerve after placing a limb of the body in Masso's Plethysmograph resulted in the increased volume of the limb due to the dilatation of the arteries in the limb. The same effect is noticed in connection with those vessels in the neck becoming very much dilated just in the same way as the vessels in the limb.

Centers of the Cardiac Nerves.

In connection with the heart there are three great centers: 1. An inhibitory center connected with the inhibitory fibers of the vagi. 2. An accelerator connected with the sympathetic fibers, and 3 The higher cerebral centers sometimes called the higher centres, which influences these other centers and explains in some way the relation of the emotions to the heart and the heart's action.

1. Inhibitory Center. The Webers, two brothers that we have been referred to already, found that this inhibitory center was located in the medulla-oblongata. Its exact location in the medulla has not yet been identified because, while a stimulation of the various parts of the medulla may yield certain results, it is difficult to distinguish the effects that are produced by the excitation of the center itself, and by the excitation of the nerves after leaving the center. Laborde has localized this center at the level of the nucleus of the hypo-glossal nerve (the 12th nerve), the vagus and spinal accessory, in the grey matter on the floor of the 4th ventricle. It was found that by separating the bulb from the spinal cord, all the reflex actions induced by nerves entering the cord were suspended while the reflex action resulting from the excitation of the tri-facial nerve (the 5th nerve), remains undisturbed. From this it is concluded that the inhibitory center is contained somewhere in the medulla, but exactly where is not known. The center of the inhibition seems to be

always active, for if the vagi are divided the heart-beat increases. This constant activity of the center may be due either to constant impulses conveyed along the afferent fibres or to the independent activity of the center apart from these afferent impulses. It would seem that the division of the vagi after all the afferent impulses have been destroyed by section of the spinal cord below the bulb does not increase the heart-action. These nervous impulses come to the center of inhibition by sensory nerves from the periphery, the splanchnics, from the abdominal cavity and also through the depressor nerve from the heart. If the splanchnic nerve be cut the afferent impulses are suspended and the heart rate is increased. The origin of the cardio-inhibitory fibres is uncertain, although it is generally believed that they enter the vagi from the spinal accessory nerves, (the 11th pair of nerves.) This is believed to be the case because on removing the spinal accessory before it joins the vagus trunk and allowing the fibers in the vagus to degenerate, cardio inhibition is destroyed, entirely destroyed. This, however, is disputed by some physiologists.

2. ACCELERATOR CENTER.—The accelerator fibers are believed to originate in the upper portion of the spinal cord, the situation of the center being unknown, although it is probably in the bulb. The accelerator center seems to be always active. This is evident from the fact that the heart rate is lowered after division of the vagi followed by the removal of the inferior cervical ganglion and the first dorsal ganglion. The same result is produced—that is, the lowering of the heart rate—by the section of the spinal cord of the upper cervical portion after the division of the vagi. There is a reflex acceleration of the heart action that arises from changes in the cardio inhibitory center and not due to the direct accelerator stimulation. If the accelerator fibers are divided, the vagi remains perfect so that the stimulation of afferent nerves increases the heart's action. It makes no difference, then, whether the acceleratory nerves are divided or solid, the stimulation of the afferent nerves produces the same result.

3. THE HIGHER CENTERS.—Various efforts have been made to localize as well as to discover higher centers, especially, in the cortex cerebri connected in some way with the inhibitory and accelerator action of these centers. Such attempts, so far, have been unsuccessful. The heart's action in connection with the heart-beat is not to a very great extent, if at all, subject to the voluntary control of the will except in very rare cases. There is no doubt but there is some connection between the higher centers representing the emotions and the cardiac centers, but the nature of these connections is as yet unknown.

INTRA-CARDIAC NERVOUS ARRANGEMENTS.—This subject has been investigated chiefly in connection with the heart of the frog. This is of considerable disadvantage in the study of the mammalian heart, for the frog's heart is more subject to intra-cardiac regulation than the mammalian heart. In the case of the frog, for example, the vagus seems to act as an inhibitory, not constantly, but only under extraordinary circumstances. When the vagus of the frog is divided, there is no increase in the heart rate. The nervous mechanism in the case of the frog's heart, is very simple. The two cardiac branches of the vagus nerves lie along the walls of the inferior vena-cava, extending to the posterior margin of the sinus venosus, forming a ganglion where the sinus and the right auricle unite. The nerves then branch out along the auriculo ventricular furrow, toward and joining the two ganglia of Bidder. From these ganglia a number of fine nerves pass underneath the endo cardium and outwards into the muscular tissue. In the mammalian heart, on the other hand, a large number of non-medullated nerves appear, forming themselves into networks, and running underneath the pericardium from the base to the apex

of the ventricle, running always in a slanting and oblique direction. These nerves can be traced to the cardiac plexus, situated at the base of the heart. They are not efferent branches of the vagus, or sympathetic, for even after dividing these cardiac nerves the characteristic inhibition and acceleration follow. If the peripheral ends of these cardiac nerves are stimulated, no effect follows in the heart rate, or in the blood pressure; but by the stimulation of the central ends, there are noticeable changes in the heart rate, and also in the blood pressure, indicating that these nerves—convey impulses to the central nervous system, resulting in a reflex action upon the heart. Some Physiologists think that the impulses are carried not from the cardiac nerves to the central nervous system, but from the cardiac nerves to the peripheral ganglia; the heart being influenced through these peripheral ganglia and not through the central nervous system. This raises the question whether the peripheral ganglia do, or do not, act as centers of the reflex activity. The excitation of the central end of the divided left anterior portion of the annulus of Vieussens becomes changed inside the first dorsal ganglion, into a motor influence transmitted by the posterior portion of the annulus. This impulse, thus changed, produces an acceleration of the heart reflexly. This would seem to indicate that certain afferent influence become changed in the sympathetic, particularly in the cardiac ganglia into effe-ent impulses which act upon the heart.

EXPERIMENTS IN CONNECTION WITH THE HEART.

After the removal of the frog's heart from the body and the breaking of all connection with the central nervous system, it still continues its rhythmical beat for some time. If then the apex of the heart is moved it (the apex) will cease to beat while the rest of the heart continues to pulsate. If the heart is continuously divided into transverse sections it will continue to beat until it is divided at the auriculo-ventricular furrow when the ventricle will cease to beat. If these unbeating parts of the dissected heart are stimulated they will respond by a single contraction even after they have ceased to beat. If the ventricle and the auricle be divided at the auriculo-ventricular furrow, the auricles will continue to beat, the ventricles ceasing. If, however, this division is made on the auricular side of the groove, especially if the septum be preserved intact the ventricle, in this case, will continue to pulsate, probably because of the passage from the auricle to the ventricle of an impulse. Gaskell by the use of the tight screwing instrument (the clamp) which he fitted around the heart was able to block entirely the nervous influences so that the ventricular beat, instead of being simultaneous with the auricular beat, beat only once for every three or fonr beats of the auricle. Stannius and Rosenberg have made experiments of considerable importance in this connection. After exposing the heart the pericardium is opened, the connective tissue between the pericardium and the ventricle is separated so as to permit the ventricle to be raised. Then a ligature is passed around exactly between the right auricle and the sinus venosus and another around the auriculo-ventricular groove.

The sinus continues to beat, the auricles and ventricle being stopped in diastole. After the latter ligature is applied the ventricle begins to beat again and sometimes the auricle also, but normally the auricle remains in diastole. It is supposed that the ganglion in the sinus affects in some way in the normal heart, the ganglion in the furrow. When the sinus ganglion is cut off, the auricle and ventricle stop because the ganglion in the groove has not enough energy to keep up the activity. The stimulation of the latter ganglion causes both auricles and ventricles to beat again, if any part of the ganglion is connected with the auricleand a part with the ventricle. This does not imply that the ganglia are necessary, however, to the heart-beat. For if the ventricle of a frog's heart is divided into sections, each part connected by muscle to each other part, stimulation of one part will cause the other parts to beat. In this case the rhythm is not transmitted by nervous imsulses. This indicates that the rhythm takes place in structures which have no nervous ganglia, as in the apex of the heart and in the heart of the fœtus in its earlier stages of development.

OTHER CIRCUMSTANCES INFLUENCING THE HEART RHYTHM. While the nervous system affects the heart, there are other influences which affects it. These are two-fold: 1. Influences depending on nutrition, and 2. Physical, mechanical and chemical influences. 1. The heart substance needs nourishment, and for this the blood supply of a necessary quality and quantity is required. In the case of the frog's heart, it continues to beat after being removed from the body and empty of blood. Soon the beating ceases. This will be aided by washing out the tissues with a saline solution If after washing a heart in this way it be attached to a perfusion canula the heart may be fed with suitable fluid, such as diluted blood or blood serum passed through the canula In this way the heart-beat may be restored artificially and kept up for a long time. When fed in this way it is found that certain substances like lactic acid result in expansion while others, like solutions of sodium hydrate, result in contraction of the ventricle. This means that the ventricular portion of the heart possesses tonicity varying with its condition and circumstances: for example: the presence of inhibitory or accelerator impulses The rhythm thus artificially produced by artificial feeding becomes generally very soon intermittent, due both to the formation of certain chemical substances and to the fact that artificial feeding is not as perfect as natural. Thus influences arise, connected with the heart nutrition, which affect the beat by influencing in some way the muscular tissue and also the nervous tissue, producing variations in the heart rhythm.

During life the heart beat is maintained by the constant supply of arterialized blood. The blood is so complex that all its elements are not of equal value to the heart for its nutrition. Various experiments have been employed by different Physiologists to discover the constituents of blood necessary for heart nutrition. A frog's heart,—for example,—supplied with a normal saline solution six per cent solution of sodium chloride, ceases to beat sooner than an empty heart. Certain of the salts that are found in the blood are required to sustain the action of the heart. For example: Sodium chloride solution, a one per cent chloride solution, is said to be isotonic. A calcium salt added to the heart after the addition of sodium chloride prolongs the heart beating, although at the same time it alters the contraction, specially the contraction of the ventricle, which falls into what is called a condition of tonic contraction. By the addition of potassium salt, the normal condition of contraction may be restored. Ringer recommends the following compound solution:

Sodium chloride, a 6 per cent solution, saturated with tribasic calcium phosphate, a hundred cubic centimetres; Potassium chloride, 1 per cent solution or acid potassium phosphate also 1 per cent solution two cubic centimetres. In regard to the mammalian heart, little has been discovered except that the blood of the same species is the best nutriment to supply the heart. It seems that in supplying the mammalian heart with the blood of a different species the heart is caused to cease beating sooner, œdema being set up in the lungs resulting in the gorging of the right side of the heart and the obstruction of the pulmonary circulation, resulting finally in the injury of the elastic cardiac muscle, causing distension, so that the diastole of the heart is impossible.

2. THE PHYSICAL AND CHEMICAL INFLUENCES.

These influences affect the structure of the heart, both muscular and nervous. We have seen already that the beat of the frog's heart is affected very materially by the beat, increasing the pulsations. The number of pulsations in the heart are increased until 40 degrees C. is reached, when the heart passes into a condition of thermal rigor. Up to 20 degrees C. the extent of the contraction continues to increase; above 20 degrees C. it diminishes, the contraction being more rapid and also of shorter duration. The cooling of the heart—as we saw, by ice—removes the rigor and by the continued application of the cooling process the heart is normally restored until it reaches 3 or 4 degrees C. when it will cease to beat. Even if the heart—the heart of the frog—is frozen, by the application of heat gradually so as to thaw out the heart not all at once but slowly, the heart will revive and begin to pulsate after a few moments, normally. In the mammalian heart it is found that by severing all the nervous connection and pouring into the heart warm blood at the normal temperature it begins to beat faster, whereas, it beats slower if a cold solution, as cold blood, is poured into the heart. It has been found that the heat must be applied to the blood in the capillaries of the heart in order to produce these results, indicating that the heart must be brought into contact with the heart substance through the blood in order to effect this increase. This idea is of great value in considering the abnormal conditions represented by fever pulsations, which become very rapid.

If an electric current is applied to the heart, of a moderate strength, the heart beat is quickened, whereas, if the current applied is very strong, the heart passes into the condition of fibrillation. A minimal stimulus produces a maximal contraction. If the stimulus is applied to the heart the effect of the stimulation will depend upon the length of time that has elapsed since the last contraction of the heart. If the time that has elapsed since the last contraction of the heart, is sufficiently long to enable the heart to recover itself, a stimulation applied will result in still further contraction. If the time, however, has not been sufficient to allow the heart to recover itself, a feeble, electrical stimulation will call forth no response, while a strong stimulation will force a response. In this last case of a strong current of stimulation, there is a cessation of the heart's action, the muscle of the ventricle at least manifesting the characteristic twitching movement, the ventricles themselves, being so twisted and dilated as to prevent blood from being driven out. Certain chemical substances affect the heart; for example: ether in small quantities, increases the heart beat, at least, in the frog's heart, while large quantities of ether will arrest the action of the heart altogether. This arrest of the heart caused by a large quantity of ether can be overcome by the addition of fresh blood to the heart. Chloroform also diminishes the heart beat. Carbonic oxide and sulphuretted hyorogen act upon the heart so as to paralyze it. Excessive carbonic acid lessens the activity of the heart, and if it is very excessive, will stop the action of the heart altogether. Sulphurous acid also very rapidly destroys the activity of the heart. The potassium salts also stop the heart in diastole. A cholorine solution, if the solution is weak, stimulates the heart's action, whereas, if the same solution is strong, it arrests the action of the heart altogether.

SECTION VIII.—II. Circulation of the Blood in the Blood Vessels.

The circulation of the blood in the blood vessels depends upon certain physical principles that regulate the movements of the current in tubes, both elastic and rigid. In the circulation of the blood in these vessels, we have to take into account, first of all, the heart force. This heart force, as we have seen, drives out the blood from the heart into the arterial circulation. 2d We have to take into account the long stretch of elastic tubing reaching from the heart, both backward and forward to the peripheries, and 3d. In the minute vessels there is a peripheral force which constitutes a constant resisting force, acting upon the blood backward to the heart. Apart from the heart rhythm, the elasticity of the arterial walls and the peripheral resistance offered by the minute capillary vessels, there are certain physical principles which explain many, perhaps all, the phenomena of the circulation. The heart force meets the peripheral resistance set in the capillaries, and sent back from these minute vessels in such a way as to promote the circulation through the entire vascular mechanism. In Physical Science the law of the equal transmission of pressure is as follows: That the pressure upon any region of the surface of a fluid, is transmitted equally, and always at right angles to any part of the surface of the fluid having an equal area.

If we take a vessel filled with water, the pressure at the bottom of the vessel will be equal to the weight of a perpendicular column of water equal to the height of the fluid, and with a base equal in area to the bottom of the fluid. At any point along the side of the vessel, or tube, in which the fluid is contained, the pressure will be equal to the weight of a column, equal to the depth of that point below the surface of the fluid with a base whose area is equal to the area of the side of the vessel.

The rapidity of the flow out of such tubular vessels of fluids is in direct proportion to the cross section area and in inverse proportion to the length of the tube. If the tube in which the liquid is contained be uniform, the fluid will run through each cross section with a certain rapidity, this rapidity diminishing with the ratio of the length of the tube and also the amount of resistance that is met with the fluid within the flow. The rapidity of the flow of the fluid will depend upon a number of considerations: 1. The calibre of the tube. 2. The length of the tube. 3 The nature of the liquid, the glutinous fluids flowing slower than the limpid fluids. 4. The pressure velocity increasing with the square root of the pressure except in small tubes, when it increases directly with the pressure. 5. The temperature, the velocity increasing with the rise of temperature, falling with the fall of temperature. 6th. The resistance. The flow is slower where resistance is greater and vice versa. This resistence is increased by the curving, jointing or the folding of the tubes, and also increases by the branching of the tube. In the latter case the branching of the tube where the tube branches off into a number of divisions, the same liquid volume passes through the same cross section area, the velocity being inversely proportional to the cross section area, therèfore diminishing as the cross section area increases. These are principles that we apply to the circulation, principles that explain the circulation of the blood. In passing from the arteries to the minute blood vessels this cross section area is constantly increasing. The blood starting from the heart has to begin with the force of the heart's action, This force is not constantly exerted, but only at intervals represented by the heart beat or the heart beat pulsations, these intermittent pulsations being compensated for by the elasticity of the arteral walls so that when the blood reaches the capillaries it is a continuous stream. This continuous current passing along the elastic arteries bears along with it the wave of contraction, representing the amplitude of the heart pulsations, the current being slower than the wave which passes along the walls. Several experiments have been made by Marey and others in connection with elastic tubes through which a fluid is passed intermittently as in the case of the blood. The results may be summarized: 1. A fluid on entering the elastic tube intermittently and quickly arouses a series of waves transmitted with a velocity independent of the current of the fluid. 2. The velocity of transmission in proportional to the elasticity of the tube and in an inverse proportion to the fluid density. 3. The extent of the wave depends upon the amount of fluid and the rapidity with which it is thrown into the tube. 4. If a fluid enters the tube in a large volume there is a backward oscillation which causes secondary waves. 5. In branching out of one tube into two tubes a very complex series of waves passes along the one tube into the other. This never takes place in the arteries because each artery has its own peculiar wave and never communicates it to the other. 6. If an elastic tube becomes suddenly narrowed or if the quantity of fluid is quickly increased or diminished a negative wave is set up. These represent the physical principles which will be applied to the circulation of the blood.

In the living circulation we find certain elements that are not found in any artificial representation of it. In the venous circulation there is such a valvular arrangement as to materially assist the circulation from the capillaries to the heart, and to prevent any recurrent blood flow. Muscular movements, especially these movements of the skeletal muscle, and even the passive movements of the limbs will assist the circulation. In respiration, also, the contraction and distension of the thoracic cavity tend to force the blood out of the chest and to draw the blood back again into the chest from the outside, thus promoting normal circulation. All these actions of the human body act as material helps to the circulation. We must remember, however, that these are simply aids that do not, or cannot, produce the circulation, because even when the muscles are resting, and when respiration is suspended for a time, there is force enough generated in the ventricular beat to drive the blood through the arterial circulation, through the capillary circulation, and through the venous circulation back to the heart again.

SECTION IX.--Physiology of the Structure of the Blood Vessels.

The blood vessels consist of arteries conveying the blood from the heart to the capillaries, through which the blood passes in close relation to the tissues of the body and to the lymph, emptying itself into the veins which carry the blood back again to the heart. The arteries, as we have said, carry the blood away from the heart. These arteries in their structure are very important. They have a strong elastic wall, and hence, remain open, even when they are cut transversely. Each artery is surrounded by a sheath of connective tissue, more or less distinct, and the arterial wall consists of several layers or coats. 1st. The tunica intina, a delicate transparent, easily broken coat, arranged longitudinally. 2nd. The tunica media, or thick, tough, elastic and contractile layers, composed of unstripped muscle fibres, arranged circularly around the vessel and in the large vessels, it consists also, of a large portion of elastic tissue. 3d. The tunica adventitia consists of bundles of connective tissue, with some muscular fibers mingled among them; these muscular fibers being situated chiefly in the deep part of the tunica, suitably arranged, also, longitudinal.

There are three kinds of arteries. 1. The arterioles, those that enter into the capillaries. 2nd. The medium sized arteries, including all the larger arteries except the aorta and pulmonary artery. 3d. The large arteries, containing a very large amount of elastic tissue. This composition of the arterical wall makes the arteries, (1) very elastic so that they distend readily, either longitudinally or transversely, returning rapidly to their original position when the pressure is removed. This elasticity is of great value in maintaining the circulation; (2), the arteries are also very contractile. On being stimulated, eather mechanically, electrically, or by nervous impulses, they lessen in calibre reducing the bore of the artery. Thus the calibre of the artery may be widened or narrowed according to the muscular activity of the arterial walls. In the larger arteries there is a predominance of the elastic fibers, and the smaller arteries of the muscular fibers—giving to the larger and to the smaller arteries their characteristic property respectively of elasticity and muscularity.

As the arteries branch out from the aorta they divide, the branches formed representing as we have seen a greater section area than they find in the larger trunk; hence the arterial sectional area increases from the aorta to the capillaries, becoming at the capillaries a very large region. The CAPILLARIES are vessels of microscopic minuteness, about 1-3000 of an inch in diameter. The capillary wall consists of a neucleated homogenous membrane continuous with the tunica adventitia. This membrane being lined by a single layer of endothelial cells, these cells being joined together at their borders or margins. These very minute capillaries are formed by division and by subdivision with almost uniform calibre, constituting net works or meshes, varying in different organs, being most minute in the lungs and the liver and larger in the case of the muscle. In these capillaries the blood current is slow, being more rapid at the center of the vessel. The delicate endothelial walls widen when the blood corpuscles pass, and narrow again when the pressure is removed. This thin wall admits of the passage of water, gas and even of corpuscles—particularly the white corpuscles —in the interchange that takes place between the blood and the tissues, through the medium of the lymph. The veins carry the blood back again from the capillaries to the heart. They have much thinner walls than the arteries and when cut across they collapse. The tunica intima in the veins is similar to and the tunica adventitia is identical with the arterial coats. The tunica media is different, consisting of white fibrous tissue with a few muscle-fibrous cells, and a little if any, elastic tissue. On account of this the veins, when empty collapse. These veins are very little elastic being simply channels through which the blood passes with only a certain amount of elasticity so as to be able to pass a certain quantity of blood necessary for the circulation. The sectional area of the veins like that of the arteries diminishes from the capillaries to the heart. The venous capacity is very much greater than the arterial capacity, the veins being able to hold all the blood normally found, both in the arteries and the veins. Inside most of the veins there are valves so arranged as to prevent the reflex current of the blood. Each of these valves consists of two flaps, projections of the inner coat placed on the opposite sides of the veins, and almost though not exactly, at the same level, so that the free margin of the one rests slightly, freely upon the free margin of the other. At the base each there is a small recess which assists the valve in supporting the column of blood above it. All of the large and middle sized vessels have within them very fine, delicate blood vessels in their walls, these blood vessels being found in the tunica adventitia. These blood vessels are supplied with nerve fibers distributed among the muscle fibers.

SECTION X.—Arterial System.

The walls of the arteries are both elastic and muscular. In the smaller arteries the muscular element and in the larger arteries the elastic element prevails. In the case of the large elastic arteries the blood enters with an intermittent flow from the heart, caused, of course, by the Ventricular beat being changed through the course of these larger arteries into a continuous flow before entering into the capillaries. At each contraction of the ventricle a volume of blood is thrown into the aorta which expands on all sides. When the ventricular diastole begins the aorta recoils the vis a tergo force, the force from behind being withdrawn ; the sigmoid valves being closed and the blood pushed along

the arterial circulation, the arteries expand as the blood flow increases and recoil as it diminishes. These movements of expansion and recoil are transmitted with diminished intensity as the blood flows from the heart. Two forces, therefore, are constantly acting in driving the blood along these vessels. The first force. the ventricular force of the systole, and 2d, the force that is produced by the elastic recoil of the vessel walls, taking place between the systoles of the ventricle. These two forces are constantly kept in regulation by the force of resistance within the vessels. As we have seen in the branching of the arteries, the cross section area is constantly increasing toward the periphery, and as the same quantity of blood is forced into the vessels at each systole, the expansion of the large vessels near the heart must be greater than the expansion of the smaller ones toward the periphery. The recoil following the expansion will also be greater, and the resistance increases as the vessels become less elastic, that is as we approach toward the periphery, because there is less yielding to the arteries : they are more rigid and solid. This produces a gradually diminishing wave along the arterial blood path. As the arteries continue to branch this wave is reflexed somewhat, the resistance increasing with the diminution of the vessel bore.

The sudden flow of blood into the arteries is also accommodated by the short lengthening of the elastic arteries. At the bends or curves in the elastic arteries, the blood produces greater sinuosity, producing the twitching movement which can be observed more particularly in connection with the temporal arteries. This is sometimes confused with the pulse. It is not the pulse. It is what is sometimes called a secondary pulse. It is caused from the rapid turn in the blood. This wave gradually lessens from the heart to the capillaries, where it ceases altogether, the blood flowing continuously through the capillary circulation. As the blood circulates in this way through the arteries, there is transmitted along the arterial walls an undulatory series of movements consisting of successive expansions and recoils, constituting the arterial pulse. We say the arterial pulse, because later we will find a venous pulse—that is in certain conditions. Some Physiologists say there is no venous pulse, that there is only the one. That is not physiologically correct. The pulse represents not the blood flow in the vessels, but the transmission of undulatory movements along the arterial walls. These movements travel at the rate of eight to ten meters per second, in the upper and lower limbs more rapidly, being about 9.4 meters per second. This represents about thirty times the rapidity of the blood flow, the blood flow not being more than half a meter in the large arteries per second, and very much less in the smaller vessels. This rate of the pulse can be estimated by recording the movements at different points of the circulation, by the use of the sphygmograph. The pulse can be felt by the finger on the carotid artery, and later at the dorsal artery of the foot. The movement of the pulse or pulse wave is a progressive one. The transmission rate from the heart to the capillaries can be estimated almost exactly. This is done by estimating the time between the pulse beat at the origin of the aorta, and the same beat at the furthest artery; measuring the distance, approximately, at least, between these points. The time occupied by pulse in its transmission from the heart to the extremities is estimated at .2 or .3 of a second, corresponding with the ventricular systole. The pulse feeling is an artificial diagnostic sign in diseased conditions, the pulse being felt most generally at the radial artery on account of its nearness to the surface and from the fact that it is supported at that point by a bone foundation so that it is quite easily felt.

The pulse normally is characterized by regularity and by rhythm. Variation, however, may arise from disease or from some transient disturbance causing an intermittent action, or by some irregularity. The pulse of high tension or an incompressible pulse, exists when an unusual amount of force is necessary in order to extinguish it. That, of course, means temporary. A pulse of low tension or a compressible one is one that may be easily extinguished. The high tension pulse marks a high blood pressure. A low tension pulse indicates a low blood pressure. These variations in pressure depend upon the action of the heart and the amount of perepheral resistance. A large pulse arises from the increase of the arterial calibre. If the pulse is very large it is called a bounding pulse. A small pulse, on the other hand, represents little if any increase in the calibre—the arterial calibre, and if the pulse is very small it is called a thready pulse. This does not mean largeness or smallness of the artery, but that the moving arterial pressure is large or small as compared, at least, with the mean blood pressure. As the blood moves along the artery the arterial pressure will be less according as the blood contents are less, and likewise the pressure upon the walls will be less when the walls give place more freely to the pressure. Hence a large pressure is often associated with a low mean pressure, and in this case it is found, e. g., after severe hemorrhage—loss of blood. The pulse movements, as we have said, may be recorder by means of the sphygmograph. The best form of the sphygmograph is that invented by Marey. It consists of a long lever moving by a screw working on a small horizontal wheel; from the axis of which there is projected a light lever. The screw point rests on a flat disc at the end of an elastic spring, which presses the disc upon the artery. The lever arm records the tracing on a blackened surface carried in front of the lever point by means of a clock work arrangement.

In the sphygmograph, by modern adjustments of this instrument, the amount of pressure on the disc made by the artery can be closely and almost exactly preserved so that at different times tracings may be taken either with the same or different pressures. The best instrument is Marey's sphygmograph with pressure graduated arrangement by Mahomed and Bramwell. Various other instruments have been devised, e. g., the sphygmoscope, a small casket with membranous bottom to which is attached an inlet and outlet tube to convey the gas, the outlet being connected with a gas burner, the membrane being placed over the pulse, the flame will show the pulse beat. By the use of a silvered glass on the pulse a photograph may be obtained by the reflection of the pulse volume by clockwork on a dial. When the artery pulsates (1) it is expanded and shortly lengthened, and (2) the blood pressure rises—the artery giving rise to the resistance that is felt when the finger presses upon the artery. In connection with the sphymograph tracing we notice: 1. An ascending line, with the upstroke or the stroke of percussion, representing the arteral expansion resulting from the ventricular systole. 2. A descending line representing the arterial elastic recoil called the downstroke. In a normal pulse the expansion and recoil are successive without any rest, the pulsations being about equal. Variations take place, however, in the pulsations according to the blood pressure as it rises or falls. The quickness or slowness of the pulse is dependent upon the proportion of time occupied by these periods. If the time of arterial expansion diminishes, the pulse is rapid, if it increases the pulse is slow. The quickness of the pulse is increased by increased heart action, a free blood flow, proximity to the heart a and considerable yielding of the walls of the artery. The different parts represented on the pulse tracing are accounted for as follows: 1. The upstroke, which is quick, brief and steady, represents the ventricular systole, the systole, the systolic wave, the opening of the semilunar valves and the rapid flow of blood from the ventricle

into the aorta and arteries, causing expansion of the arteries. 2. The downstroke represents the blood flow from the arteries to the capillaries and is prolonged, gradual and vibratory. 3. The large dicrotic wave on the downstroke represents the closure of the semilunar valves. 4. Following the upstroke or systolic wave during ventracular contraction we have the pre-dicrotic or second ventricular systolic wave represented in the curve tracing at the apex. 5. In some tracings where the pulse is irregular there are secondary waves arising from the elastic vibrations of the arterial walls. The vibrations of pressure are more or less constant. Sometimes the vibration becomes so irregular that it produces a partial upstroke of the pulse during the downstroke, causing a double beat during each ventricular beat. This is called a dicrotic pulse. The pulse is always dicrotic normally and hence the slight dicrotism gives origin to the name dicrotic wave. Much discussion has taken place as to the cause of this wave.

Much discussion has taken place among Physiologists, as to the origin or causes of this pulse wave. These opinions may be summarized under three heads:

1. Some Physiologists claim that there are two reflected secondary waves; one originating from the closure of the semilunar valves and another from the small arteries at the periphery starting backward, as a reflection of the main pulseway. This wave is supposed to be reflected backward from the periphery and travels toward the heart, reaching a given point in the arterial blood path after the main pulse wave has passed that point traveling in the opposite direction. If this is the case, then, in the tracing from the peripheral artery the dicrotic wave should arise nearer to the close of the upstroke, representing, therefore, the highest point that is reached by the pulsation, than in the case of an artery nearer to the heart. Measurements have shown that the difference between the primary and the secondary waves is greater in the smaller arteries than in the larger arteries nearer to the heart. This would prove that the dicrotic wave cannot be due to any secondary backward wave; hence, this explanation is improbable.

2. The opinion that is supported by most of the Physiologists, is, that it is due to the slight rise of the arterial pressure arising from the closure of the sigmoid valves, and that this secondary wave follows after the main pulse wave from the opening into the aorta as a secondary wave. In this way the reflection takes place wholly from the heart, and it moves constantly toward the periphery, being modified in its course and giving rise to vibrations. This would make the closure of the aortic valve simultaneous with the beginning of the dicrotic wave. When the ventricular contraction takes place, a primary wave is transmitted along the arteries to the capillaries where it is destroyed. By the recoil of the walls of the aorta, the aortic valves close; by the closure of these valves the secondary wave is reflected from the aorta to the periphery. It is this secondary reflected wave that produces the dicrotic expansion of the vessels, marking the dicrotic wave of the pulse tracing. The primary pulse wave passes gradually along the arteries from the heart. Similarly the dicrotic wave is marked farther down the curve, the farther the artery is from the heart. The wave becomes less marked as it travels farther from the origin—the origin in the aorta—hence, the wave becomes less distinct toward the periphery.

The dicrotic wave is more marked, as the primary wave is stronger, both of these depending on the strength of the ventricular systole. When the blood pressure of the small arteries becomes less, the dicrotic wave is greater as the wall of the vessels is able to yield more freely. The more full an artery is of blood, there is less yielding in the vessel wall, and the dicrotic wave becomes less marked and more steady. Other secondary waves may also arise to render irregular the primary wave. Where there are three of these waves it is called tricrotic. Where there are many of these waves it is called polycrotic. If these secondary waves appear, only, in the down stroke, the curve is called katacrotic. Sometimes, however, one wave appears on the ascending part of the main curve, in which case it is called the anacrotic, associated in some way with irregular ventricular action, or a diseased condition of the ventricle.

3d. Foster explains the dicrotism without any reference to the closure of the semilunar valves. This closure, he says, is an effect, not the cause of the dicrotic wave. On the sudden cessation of the flow of the blood from the ventricles, a negative pressure is set up posterior to the blood, affecting the calibre of the vessels due to the vessels' elasticity, the result being that the vessel shrinks—particularly the vessel wall. This shrinkage becomes too great on account of the inertia of the walls, and there at once arises a secondary expansion, that is, you have an excessive shrinkage of the arterial wall, and when that excess shrinkage comes into contact with the inertia of the vessel wall, then there is produced this wave. This is assisted by the similar shrinkage and expansion of the blood. This gives rise to a series of successive waves, traveling from the root of the aorta along the arterial walls with gradually diminishing force, and produces the dicrotic wave. This dicrotic wave, thus produced, pulls after it the blood that has been, by reflux action, drawn back toward the heart and resulting in arterial expansion, and recoil according to the ventricular beats

The sphygmograph cannot give a perfect tracing of the pulse, particularly the pressure line of the pulse, on account of the varying quantity of tissue lying between the surface of the skin and the arterial wall. On account of this the valve of the sphygmograph is relative, not absolute. The normal pulse rate in the male is about 72 per minute, and in the female from 78 to 80. This, however, is to be taken simp'y as an average, because in the healthy individual, it may vary all the way from 50 to 100. In the new born child it varies from 130 to 140, gradually diminishing till about the fifteenth year, when it ranges from 75 to 78. From sixty years of age it tends to rise gradually toward 80. The pulse is said, by some Physiologists, to be affected by the height of the body, being quicker, as they say, in the short body, in the longer body slower.

The pulse is affected by different bodily conditions, such as active exercise, a rise in the blood pressure, nervousness tending to raise the pulse. A rise of the temperature will also quicken the pulse. When the individual is lying down it is slower and when standing or walking it becomes faster. In the morning after rising it is slower, gradually rising to mid day, after which it decreases unless it is raised by active exercise or some other exciting cause. Toward evening it becomes slower, gradually becoming slower during sleep until about midnight, and after midnight it gradually becomes faster. The pulse beat affects more or less the entire bodily system, causing oscilations of the body which may be noted in some circumstances very distinctly. The pulse beats, also, visibly affect the teeth, nasal cavity, the larynx, the tympanum of the ear, and the eyes, producing certain movements in the internal parts of the eye and of the brain, especially manifest in the vibratory movements of the membrane at the junction of the cranial bones in the case of the child.

In the smaller arteries there is a considerable quantity of unstriped muscle which may produce contractile movements. These contractile movementsare independent of the pulse and may be either temporary or permanent, but the rythmical contraction usually results from the action of the nervous system on the blood circulation. This contraction, muscular contraction, affects, more or less, the arterial blood pressure, either assisting or hindering the blood flow and normally regulating the blood supply to the capillaries under the control of the arteries. These contractions in the different arteries supply the capillaries with a constant flow of blood, setting up what are called, a series of local circulations which balance each other, producing the natural blood flow to the different capillary regions.

In this way the circulation of the blood is maintained uniform, in the minute vessels of the brain, the minute vessels of the abdomen, of the liver and of the spleen, and especially the correlated circulation being regulated in such a way as to preserve a balace between the liver and spleen, the abdomen and lower parts of the body, the brain and thyroid glands. They are regulated so as preserve equilibrium. If the stethescope is placed over a large artery a sound may be heard; this sound being produced by the flow of the blood through the vessel under compression by the force of the stethescope. When the flow of blood passes beyond this pressure, the rapidity of the blood flow causes oscilations. These sounds are not produced by the oscilation of the arterial walls, although the elasticity of the arterial walls assisted by lessened peripheral resistance, aids the blood current, the blood passing away very freely and rapidly.

SECTION XI. Capillary Circulation.

The capillary circulation may be easily studied in connection with the frog's foot, the lung of the frog and any other of the organs in which fine capillaries are found. Each capillary of this minute network extending through the body constitutes a tube, the diameter of the finest of these tubes being from .005 to .020 part of a millimeter and extending in length from 1 to 5 mm. The number of these small capillaries depends upon the activity of the tissue, being more numerous in the active organs and active tissues. These minute vessels anastomose, forming network that vary in the different parts of the body. The circulation in the capillaries, small arteries and veins is continuous, there being normally no pulse, the intermittency of action arising in the larger vessels on account of ventricular beat being overcome before the blood reaches the minute vessels. The walls of the minute vessels are very delicate, the calibre of the vessels varying so that in the lungs and among the muscle and nervous tissues where the blood performs its most important functions, the blood is collected in very minute vessels, moving slowly and over a very large surface. The capillary walls are composed of a very fine layer of endothelial cells, margin to margin closely joined together by cement matter. These delecate cellular walls become thicker we approach toward the small veins and arteries. This fine cellular character of the wall is of great importance physiologically in the interchanges taking place between the blood and the tissues. The chief vital characteristic of the capillaries is contractibility upon which depends the elasticity and distension of the vessels in the modification of the calibre. On the application of stimulation the walls contract, the power of contraction residing in the endothelial cells lining these walls. This contraction is intimately connected with the variation of the blood supply, the vessels contracting or relaxing according to the requirements of the tissues. The existence and arrangement of these capillaries in the different tissues is such as to promote efficient functional activity. If the tissue or organ is very active the muscles of the body of the capillaries are arranged in long meshes, in the capillaries are very closely connected into a plexus; if the tissue organ is less active the arrangement is less minute and extensive. This arrangement is always in harmony with the structure of the tissue or organs, e. g., in the connective tissue they assume irregular shapes, in the small cutaneous papillæ they form little circles. The capillary circulation is due to the heart force modified and modulated by the circulation through the vessels. Some physiologists consider that it is also influenced by the drawing action of a tissues through which the capillaries pass. This is proved by the increased amount of blood attracted to a tissue that is very active, in order to sustain its nutrition, e. g. in the lactation of the mammary glands. This force represents the need of blood and may be considered as an active element along with the heart force is sustaining the circulation.

In the capillary circulation there is no pulse, the pulse movement transmitted along the arterial walls being extinguished mainly before the blood flow enters the capillaries, and finally, by the great resistance, arising from the minute subdivision of the capillaries. In the case of great distension in the smaller arteries and veins, there is a venous pulse. There may be, also, an abnormal capillary pulse. This is produced by the compression of the muscles in which the capillaries are situated, as for example, in the case of swellings due to inflammation in which a capillary pulse produces throbbing.

The current of blood varies in its rapidity, being more rapid in the smaller arteries than in the smaller veins. In the smallest capillaries the current seems to be almost uniform, at least in the vessels of the same size. This, however, is subject to variation even in the smallest vessels on account of the variation in the intensity of the heart beat. In the larger capillaries the red corpuscles travel with great rapidity along the center of the stream. Sometimes two or three of these red corpuscles travel abreast of each other while the white corpuscles move along the slower part of the stream close to the vessel walls. The red corpuscles, as we have said, move along the central part of the stream keeping separate, normally, from each other, unless in the case of their passing into the smaller capillaries, in which they move through the minute channels in single file, squeezing its bending and elastic substance through the narrow bore of the vessel, afterwards regaining their normal shape. The colorless corpuscles move chiefly in close contact with one another and with the vessel wall, moving much slower than the red corpuscles and adhering together, and closely adhering to the vessel wall even after the red corpuscles have squeezed themselves past the white corpuscles. This fact, that is, their moving less rapidly than the red corpuscles, close to the walls is due to their lighter specific gravity —that is, of the white corpuscles—the more dense corpuscles being driven out into the middle of the stream, the red corpuscles being slightly denser than the blood plasma, and the white corpuscles slightly less dense than the plasma. In addition to the density of the blood corpuscles the friction is always less at the middle of the stream than at the sides. This is evident from the fact that the white corpuscles along the sides of the stream are clearly separated from the red corpuscles in the middle of the stream by a narrow channel of blood plasma. In some cases the white corpuscles in addition to adhering to the vessel wall, passes through the vessel walls, this process of migration taking place between the minute cells of the endothelium lining of the walls. The leucocyte changes its shape very easily and thus, in its amoeboid movements passes through the vessel wall into the lymph.

This process may be seen in active operation under the microscope, by setting up an artificial inflammation in the mesentery of a frog by exposing it to the air for some time. In normal, healthy conditions it would seem that there exists a close relation between the vessel walls and the blood, according to which the adhesion of the corpuscles to the vessel walls is regulated, determin-

ing the normal flow of the blood along the side of the vessel. When inflammation is induced, the tendency to adhere is greatly increased, to such an extent as sometimes to stop the blood current, as the blood passes through the vessel. This may be increased to such an extent by the accumulation of these white corpuscles, and by the gradual lessening of the channel through which the blood passes until stagnation of the blood is produced, called stasis. In this case the red and the white corpuscles become mixed together in a mass, the two kinds of corpusles, red and white, passing through the vessel wall into the lymph spaces. In this case we have the condition, that we mentioned before in connection with the blood, diapedesis. In normal conditions the changes occurring in the vessel walls, assist the migration of these white corpuscles. The lymph that surrounds this area where the inflammation is set up being profuse with proteid matter. This would seem to indicate that the conditions of the tissues in which the vessel wall is located, promotes the circulation of the blood, particularly, the circulation of the white corpuscles in the blood. The speed of the blood varies from the wall toward the center of the vessel. The speed of the red corpuscles at the center of the stream is more rapid, therefore, than the speed of the white corpuscles, at the sides being markedly uniform through the course of the capillaries. The blood pressure within the capillaries is normally low, being liable to change, on account of the elasticity of the vessel wall causing normal changes of the vessel calibre. The lowness of the blood pressure is evident from the fact that on cutting the muscle, the blood trickles from the capillaries very slowly. This same result may be produced by compressing the skin until the cuticle becomes white and pallid on account of the expulsion of the blood out of the capillaries in the tissue. This pressure of the capillaries has been estimated by various Physiologists as ranging from 25 to 54 mm. In the pressure of the capillaries there is, also, an element which arises from the character of the blood. The resistance to the flow of blood seems to increase when the oxygen, carried by the red corpuscles, is diminished. In this way the blood and the vessel walls affect the pressure, and also the blood flow; the one influence molding and directing the other.

SECTION XII. The Venous Circulation.

The vein walls are thinner, more expansible and less elastic than the arterial walls. As we said before, they contain fibrous muscular tissues and a little elastic tissue. The veins freely anastomose so that that there is a free circulation of the blood through the venous system. The venous blood circulation is dependent upon, (1) a suction action of the heart drawing the blood away from the veins toward the heart, (2) It depends upon muscular activity, acting upon veins in such a way as to press them while opening the venous valves toward the heart and thus aiding the blood flow in the direction of the heart. (3) It is aided by the diminished blood pressure in the veins as compared with the arteries and (4) It is also aided by respiratory action. This respiratory action assists the current of blood in its flow in the direction of the heart. In the case of the opening of a vein the blood flow is aided by muscular activity, producing in the case of the vein an even current of blood because of the absence of elasticity found in the veins as compared with the elasticity found in the arteries The force of gravity, also acts freely upon the blood flow. This is seen, for example, in the hanging downwards of the limbs, producing dilatation of the veins with the characteristic swollen appearance of the veins and the bluish color of the skin. This may be restored by lifting up the arm. When the limb is in this position the veins rapidly empty themselves; thus the flow of blood is much more free in the veins than it is in the arteries. The only, or at least the chief check in the case of the veins is the action of the muscles which drive the blood in the direction of the heart; the valvular arrangement of the veins preventing any recurrent blood flow. The veins are found to possess no valves where the external pressure is absent, for example, in the brain and the internal portion of the bones. This valvular arrangement is of great value in connection with the vertical position of the body, as these valves prevent the blood from passing down to the lower extremities of the body, and also, promoting the circulation toward the heart. In addition to this the force of the blood presses the valves open toward the heart, at the same time preventing the blood from making its way backward to the peripheral extremities of the veins. In some cases we find the blood pressure is insufficient to carry off the blood into the circulation, the veins in such a case setting up a pulsation which has been called the secondary heart. Normally, as we said, there is no venous pulse, sometimes, however, the pulse wave passes on through the capillaries into the veins.

This pulse, as seen, for example, in the veins of the neck, is supposed to be produced by some obstacle that prevents the passage of the blood from the right auricle to the right ventricle. The pulse, in this case, is uniform in its time with the systole of the auricle. During the right ventricular systole the right auriculo-ventricular valve closes. Sometimes, however, this valve does not close sufficiently and as a result there is an undulatory movement transmitted along the wall of the superior vena cava to the veins of the neck, in this way producing the pulse of the venous circulation When the auricle and ventricle are in diastole the blood passes to the heart. This pulse arises from the imperfect activity of the jugular valve permitting the wave to pass along the jugular vein, causing the venous pulse of the neck. On the other hand, when the left auriculo-ventricular valve is weakened in some way, the right auricle becomes engorged with blood, and as a result a wave of contraction is transmitted to the veins. In the case of a tumor within the veins, there is sometimes produced such rigidity as to destroy elasticity and there is such an expansion of the capillaries that the wave which originates from the ventricular beat is transmitted through the capillaries to the veins. In connection with the salivary glands when the small arteries are dilated the blood may flow through these into the veins in a rapid and a pulsating stream, causing in these glands a venous pulse. When the heart begins to act feebly, for example, in old age, there may be or often is a very characteristic venous pulse, sometimes called the old age pulse.

SECTION XIII. Pulmonary and Portal Circulation.

In the pulmonary circulation the venous blood is returned by the veins to the right auricle, passing to the right ventricle on the contraction of the auricle, and on contraction of the ventricle, is passed along the pulmonary artery to the lungs in order to be cleansed. After having passed through the lung circuit it returns pure as arterial blood to the left auricle through the pulmonary vein. This pulmonary circulation, although essentially the same as the systemic circulation, differs in some particulars. The pulmonary circulation is small in extent, compared with the systemic. As the ventricles empty simultaneously and are of equal capacity, it is interesting to follow the circulation in the lungs. In the pulmonary circulation as compared with the systemic, the resistance is less, and therefore in the case of the ventricular contraction there is less resistance to be overcome by the right than by the left ventricle. The structure of the heart is such as to be prepared for this. The muscular wall of the left ventricle is very much thicker than that of the right. Hence the force of contraction in the case of

the right ventricle is very much less than that of the left ventricle. It is impossible to estimate the blood pressure or the rate of the blood flow in connection with the pulmonary circulation, because the pulmonary circulation cannot be reached unless after destroying the respiratory mechanism, and artificial respiration is not sufficient even if such artificial respiration could be produced to give a normal pulmonary circulation. The pulmonary artery, like the right ventricle as compared with the aorta and the left ventricle, has a very thin wall, indicating the lessening of the pressure.

The pulmonary artery conveying the venous blood from the heart is subdivided into a number of branches, the very minute vessels passing into the plexuses of the capillaries on the walls of the air vessels of the lungs. Arising out of these plexuses are the veins which collect the blood, pouring it into four larger veins, two for each lung, carrying it back by the pulmonary veins to the left auricle The pressure of the pulmonary artery is much less than that in the aorta, the proportion being estimated about 2 to 5. The pulmonary system lies inside the thoracic cavity, although outside of the lungs, except in the case of the lung capillaries, hence, when the lungs are filled with air in inspiration the large vessels become expanded while the capillaries lining the surface of the lungs are subject to the same amount of pressure as the surface of the lungs upon which the entire air in the lungs may act. In this way the capillaries and the pulmonary veins are greatly assisted in freely circulating the blood, by this pressure, whereas, the pulmonary artery is weakened in its action. This, however, is counterbalanced to a large extent by the structure of the walls of the arteries as compared with the veins, the arteries being much more firm and solid. In this way the lung contraction in connection with the muscle of respiration materially aids the process of circulation in the pulmonary system, especially the activity of the right ventricle. The lungs expand on account of the internal pressure being greater than the external pressure in the pleural cavities. If this expansion is full in inspiration the elastic action exerted by them amounts to 30 mm of mercury. External to the lungs there is a pressure in the thoracic cavity bearing upon the surface of the heart and other organs equal to the pressure of the air minus the elastic force of the lungs, themselves, that is, 730 mm. The fine walls of the veins will yield to pressure easily during inspiration, lessening the pressure, while the thicker walls of the arteries will yield less, and in this way the blood flow from the lung capillaries to the heart is promoted. Expiration will have an opposite effect. The effect of inspiration upon the pulmonary capillaries and smaller vessels of the lungs is to assist the blood flow while expiration hinders it. This is due in inspiration to an increase of the calibre of the pulmonary vessels driving the blood to the lungs.

The blood rate of the pulmonary is greater than of the systemic circulation, and it is greater in the pulmonary veins than in the arteries. This is necessary in order to accommodate the same volume of blood in the pulmonary as in the systemic circulation. The right ventricle has sufficient force within itself to perform its work. This is evident from the fact that apart from the normal chest contraction, if the thoracic cavity be opened, the heart can perform its work without any respiratory action, if the respiration is preserved artificially. The pulmonary circulation, therefore, is much more simple than the systemic circulation.

PORTAL CIRCULATION.

In the portal circulation there is one fact that requires particular notice, the passage of the blood through two capillary circulations in the abdomen and the liver. The branches of the abdominal arteries carry the blood to the stomach, spleen, pancreas and the intestines, these branching off in the different organs in a series of capillary plexuses. Arising out of these plexuses are the veins joining together to form larger veins, the blood flowing through two veins, the splenic and mesenteric, into the portal vein through which it is passed to the liver, in which it is circulated by means of minutely branching capillaries collected into a plexus. Springing out of these plexuses in the liver lobules are the origins of the hepatic vein through which the blood is carried from the liver to the heart, by the inferior vena cava. If the portal vein is tied, all the abdominal vessels become expanded, causing congestion of the abdomen, producing rapid diminution of blood pressure and death. Sometimes the ventricular force produces a wave of contraction which is transmitted through the inferior vena cava and the liver, producing a liver pulse. In fact the liver normally follows the action of the heart in the inverse order contracting with each diastole, and distending with each systole of the heart.

SECTION XIV. Innervation of the Blood Vessels.

In the case of all the arteries it is found that muscular fibers are part of the lining of the vessel wall chiefly in the tunica media. This muscularity increases in the smaller arteries. The fibers of nerves are found largely distributed among the arteries, being collected around the muscular walls in small plexuses. If these nerve fibers are stimulated they respond by conveying the impulse along the muscular wall, producing contraction, resulting in the diminution of the vessel calibre. Similarly, the veins are muscular in their walls, although there is much greater variation among the veins. The nerves terminating in the muscle walls of the veins, also, convey impulses resulting in contraction of the vessel. This constriction and dilatation of the vessels is in the vessels themselves, under the control of the nerve fibers so that in all the arteries of the body there is a nervous influence imparted to the muscular walls from the nerves. These nerves are called the vaso-motor nerves. The muscularity of the walls may be represented as passing through three stages. 1st. Contraction of the muscle constricting the artery. 2d. Distension of the muscle dilating the artery. 3d. Moderate contraction of the muscle, in which case the artery is not greatly constricted or greatly dilated. This latter is called the tonic contraction or arterial tone representing the normal condition of many arteries for a long time. This subject was for a long time the vexed question in Physiology. It is not more than 50 years since the muscularity of the middle coat of the arteries was established. Henle first declared that "while the movement of the blood depends on the heart, its distribution depends on the blood vessels." It was known that the walls of these vessels were subject to contractility and that the nerves terminated in these muscular walls. From this it was taken as proved that the blood vessels were controlled by the nerves and that these nerves under stimulation influenced the contractility. It was discovered that by dividing the cervical sympathetic or extirpating the superior cervical ganglion the circulation was increased on the same side and the temperature raised. If the sympathetic is cut, in the neck there is dilatation of the vessels and a rise in the temperature. If the cephalic part of the nerve cut, be stimulated, it is found that the dilated vessels of the face soon begin to contract and the temperature falls, this contraction gradually increasing and soon passing away. On the withdrawal of the stimulus, the vessels again dilate. Therefore, it is concluded that there are nerve fibers in the sympathetic which influence the contractility of the vessels by constriction.

The spinal cord is found to originate certain fibres that produce the same result. The submaxillary gland is well supplied with blood vessels, being supplied with nerves from the cervical sympathetic and from the chorda tympani, arising from the seventh cranial nerve and joining the lingual branch of the 5th nerve. After laying bare the submaxillary gland isolating the nerves into the gland, the vein was opened and the blood was found to be dark. The sympathetic branch was ligated after which the dark blood became as bright as scarlet. Stimulation was then applied to the nerve, between the gland and ligature, causing the blood to become dark again. Then the chorda tympani was ligatured and the end in connection with the gland stimulated, the blood flowing intermittently from the vein of a bright scarlet color. In the chorda tympania there must be, therefore, vaso-motor fibres producing the very opposite result from that noticed in the case of the stimulation of the cervical sympathetic; hence we come to the conclusion that there is a two-fold influence exercised upon the vessels as to size and quantity of blood in these vessels by the nerve fibres. Certain nerve fibres producing constriction of the vessels, vaso-constrictor nerves and certain nerve fibres producing dilatation of the vessels, vaso-dilator nerves. In connection with the veins, the vaso motor influences are also apparent. If the aorta is subjected to pressure under the left subclavian artery, the portalvein ceases to receive blood from the intestinal arteries and still continues to hold a quantity of blood. If the splanchnic nerve is divided and the peripheral end stimulated, the portal vein contracts and drives out the blood into the capillaries of the liver. If the crural artery is ligatured and the sciatic nerve be divided, the application of stimulation to the peripheral end of the cut nerve produces contraction of the veins in the limbs; the contraction, if the stimulation is continued, entirely contracting the vessel so as to destroy its bore. Afterwards, withdrawing, stimulation the contraction disappears. The same principle is applied to the veins as to the arteries in connection with the vaso-motor nerves. Nearly all the nerves of the body in this way are brought into play to influence in some way a part of the vascular area, the influence being either constrictor or dilator.

1. VASO-MOTOR FIBERS—There are two kinds of vaso-motor fibers, the vaso-dilator and the vaso-constrictor. These fibers originate in the central nervous system, the brain or the spinal cord. So far as the human subject is concerned, the vaso-constrictor fibers arise in the middle region of the spinal cord, or separate from the cerebro-spinal system by fibers which arise in this region. All the vaso-constrictor fibers seem to leave the spinal cord from the anterior roots of the spinal nerves, and after going through the branches of the viscera join the abdominal thoracic chains of the sympathetic ganglia. On entering these ganglia from the anterior roots and the visceral branches, they are medullated. After leaving these sympathetic ganglia, and before entering the blood vessels they become non-medullated, losing their medullated character in the ganglia. In the case of the vaso-dilator fibers, some of them run along side by side with the vaso-constrictor fibers; others, however, run in an independent course. In the case of the nerves of the cranial and sacral regions where no vaso-constrictor fibers are found, the vaso-dilator fibers have been very distinctly followed. The dilator fibers for the submaxillary gland can be followed in the chorda tympani to the 7th nerve. Along the lingual nerve there are, also, dilator fibers to the tongue, as the application of stimulation to the lingual nerves produces dilatation of the blood vessels in the tongue. The eye and the nose receive dilator fibers from the trigeimnal, and parotid gland from the ramus tympanicus of the glasso-pharyngeal nerve.

In the limb nerves the dilator fibers are less easily detected because of their junction with the vaso-constrictor fibers; although it is thought by some Physiologists that the dilator fibers pass directly through the anterior spinal roots. In line with this idea it is stated by these Physiologists that the vaso-dilator fibers arise from all portions of the spinal cord as well as the medulla while the vaso-constrictor arise from a special portion of the cord passing indirectly through the splanchnic ganglia on their circuit to the different blood vessels, in connection with the body. The vaso-dilator fibers, also, differ from the vaso-constrictor fibers in retaining their medullated character until they are close to their terminal connection with the blood vessels. The vaso-constrictor fibers, at least, in the sympathetic, splanchnic and cutaneous nerves are constantly active, imparting a tonic constriction to the vessels, the division of these constrictor fibers resulting in the loss of arterial tone. The dilator fibers, on the other hand, are not in constant operation. The section of these fibers does not produce any permanent effect, but simply a temporary dilatation, in all probability, due to the irritation of the nerves by cutting rather than due to stimulation. These differences are most interesting from the fact that these two fibers are bound up in the same nerve, at least, as we said before, in a great number of cases these two fibers are bound up in the same nerve. It is only by these differences between the constrictor and dilator fibers that the fibers can be detected separately, otherwise, the action of the one fiber, might and would counteract the action of the other fiber. It seems to be more difficult to irritate the constrictor than the dilator fibers. If the constrictor and dilator fibers are stimulated at the same time and with an equal amount of stimulation in the submaxillary nerves the constrictor action prevails where as, after stimulation is withdrawn, dilatation will result.

The effect of heat and of cold upon the fibers is greater in the constrictor than in the dilator fibers, the heat increasing, and the cold diminishing the effect of contraction or of dilatation. A single induction shock affects slightly the constrictors, and very appreciably the dilator fibers, continuous shocks, on the other hand, affect the constrictor fibers very strongly; in some cases producing tetanus. If the two fibers are cut—the vaso dilator and the vaso-constrictor—away from their central origin, degeneration will set in more rapidly in the constrictor fibers than in the dilator fibers.

This vaso-dilator action is most intimately connected with the blood circulation. As we have seen, before, the blood current in the system is regulated almost wholly by the tonic condition of the arteries. Normally, these minute arteries are in a tonic state of contraction, producing largely, the peripheral resistance, which is so important in connection with blood pressure, and also, with the blood flow. In addition to this general effect upon the circulation as a whole, we find also, that the circulation is affected in a separate local area that is, vaso-motor changes, have both a general and a local influence upon the circulation. Arterial constriction in a local area results in lessening the flow of the blood through certain arteries, increasing the general arterial pressure, and causing the blood to flow more freely through the arterial channels; on the other hand, arterial dilatation results in increased blood flow through certain arteries, in lessening the general blood pressure, and in producing a lessened amount of blood in the other arteries. These effects vary as the local area affected by constriction or dilatation, is larger or smaller. In this way the central nervous system utilizes these vaso motor changes in order to govern the blood supply in the different parts of the body, influencing the blood supply, either in a general way, or in a particular way in a certain area, or part of the body.

2. Vaso-motor Centers.—These vaso-motor nerves, that we have spoken about, the constrictor and the dilator fibers, branch out, as we have seen, from

the sympathetic ganglia, these ganglia being subject to the influences of the spinal cord, whose ganglia, lying at different levels in the spinal cord, are under the control of the medullary centers. There are thus found to be three centers of vaso-motor influences. 1st. The great center, commonly called the vaso-motor center in the medulla, communicating by the intracranial and the intra-spinal nerves, with the second center, namely, the ganglia in the cerebro spinal axis, these ganglia representing the 2nd center communicating with the 3d center, namely, sympathetic ganglia by the spinal and the cranial nerves; these sympathetic ganglia sending out branches to the muscular walls of the vessels.

(a) The vaso-constrictor fibers have been found to arise from the middle portion of the spinal cord, passing into the sympathetic ganglia chain from which they pass by their branches to the superficial tissues of the body, the alimentary canal, the glands and their different appendages. If the spinal cord is divided in the lower dorsal region, and later in the upper dorsal region, noticeable effects are found to follow, for example after the division of the lower dorsal region the tonic influence is cut off from the lower extremities, causing the dilatation of the blood vessels, at the same time diminishing the peripheral resistance which is followed by a fall in the blood pressure. After the division of the upper dorsal region, the vessels of the abdomen, of the head and of the face become dilated and the blood pressure falls very markedly. This indicates that the tonic influences which affect the skin, the viscera and the lower extremities, emanates from some part of the central nervous system, above the upper dorsal portion of the spinal cord. The same results will be found to follow the division of the spinal cord close to the lower part of the medulla. If the cut fibers in any of these cases be stimulated, dilatation will give place to constriction. Hence the distension of the vessels of the trunk and limbs must have been caused by the interruption of vaso motor influences, the cutting off of these vaso-motor influences by the section, or the division of the spinal cord. If the whole of the brain be removed down to the upper parts of the medulla no distension and no fall in the blood pressure follows, or at least the fall is very slight. From these experiments it is concluded that there must be a vaso-motor center in the medulla oblongata located on the floor of the 4th ventricle, somewhere in the regional area of the calamus scriptorius and the corpora quadrigemina. Some experimenters have divided the bulb into sections, transverse sections, thus attempting to locate the center in a region at the lower border of the corpora quadrigemina lying in a bilateral position on both sides of the median line, said by some Physiologists, to correspond with the anterior nucleus of Clark. (b) There are also spinal centers in the spinal cord. Some experiments for example, in connection with the dog have shown us that by dividing the cord at the point of the junction between the dorsal and the lumbar portions of the spinal cord, thus dividing the animal body into two parts so as to sever the lumbar region from cerebral influence, these experimenters have found that the lower extremities of the body of the dog are warmer than the upper extremities, and the arteries of the lower extremities are more active than the arteries in the upper extremities.

This change in the blood must be due to the removal of the vaso-constrictor influences of the great vaso-motor center in the medulla. From this it is concluded that vaso-motor centers must be found in the spinal cord. Reflex action takes place in connection with these centers. After the section of the spinal cord the 3d vertebra, if the central end of the brachial nerves be stimulated, the vessels of the front limb are dilated. If the sciatic nerve be divided and then the central end be stimulated, the blood pressure will rise. This rise in the blood pressure arises from constriction. If the sensory nerves in any limb be stimulated after the section of the spinal cord in the middle thoracic region then the vessels in the other limb will be constricted reflexly, indicating that reflex action takes place through these spinal centers: that are found in the spinal cord. (c.) In addition to these two centers we have also sympathetic centers. It is said by some Physiologists that even after the extirpation of the medullary centers and of the spinal centers there is still left a certain tonicity in the vascular mechanism. The lower part of the spinal cord has been completely removed. For some time after the removal, the lower extremities remain dilated, on account of the dilatation of the blood vessels, after distention of the blood vessels passes away, the limbs return to their normal condition, assuming tonic constriction altogether independent of the spinal cord. This proves that in connection with the sympathetic ganglia, there are centers. These centers are also the seat of reflex action, acting as the seat of other motor reflexes. If one of the branches of the annulus of Vieussens be divided and if the end still connected with the first thoracic ganglion be stimulated, after separating the branches connecting the ganglion with the spinal cord, contraction is apparent in the blood vessels of the ears and nose and submaxillary gland. This would seem to indicate that these sympathetic centers as well as the spinal centers and not simply subsidiary centers, but in a sense independent centers of vaso-motor action. In connection with some blood vessels certain rhythmical contractions are noticeable, these being entirely independent of the central nervous system. These are said to be seen in the median artery in the ear of a white rabbit and are said to originate in the emission of impulses from the vaso-motor centres. If the thoracic cavity be opened and the vagi divided, certain vibratory movements are noticed in connection with the blood pressure tracing. These vibrations are complicated and are probably due to variation in the respiratory center acting upon the vaso-motor centers through a process of irritation.

There is a certain relation between the cerebrum and the vaso-motor centers. By the application of stimulation to the cortex cerebri, and the other portions of the brain, it is found that the blood pressure is raised. This variation in the blood pressure is believed by some Physiologists to be the result of reflex actions, the cerebral centers originating impulses that are communicated to the vaso-motor. Afferent impulses originated in the blood vessels or in the terminal organs of the sensory fibers may excite the vaso-motor nerves reflexly. The limb of a rabbit was severed entirely from the trunk, leaving the sciatic nerve intact. The peripheral end of the crural artery was subjected to stimulation, that used in this case being the nitrate of silver. This stimulation was followed by an increase of blood pressure, and then after a few minutes by a fall in the blood pressure. This fall in the blood pressure being due to the stimulation conveyed by afferent nerves in the vessels and sent through the sciatic nerve to the vaso-motor center. Stimulation, therefore, of the sensory nerves produces reflexly constriction and dilatation. If food is placed in the mouth the nerves of taste originate certain influences producing efferent impulses in the centers, which pass out along the chorda tympani and other nerves to the salivary glands, resulting in the distension of the blood vessels, increasing the blood supply in these glands and exciting secretion. This may apply to the two sides of the body, as in the case of irritation of the mucous membrane on the one side of the nasal cavity producing a distension of the two sides of the head. The effect in this case is more noticeable on the side of stimulation. In the same way impulses may be transmitted along the vagus or along any of the sensory nerves to the center, producing

activity of the dilator fibers in chorda tympani or other nerves, resulting in an increased blood supply to the salivary glands. The muscular blood vessels, that is, the blood vessels that are deeply imbedded in the muscles, seem to be distended by vaso-motor influences; the dilator fibers being aroused to activity by the impulses that are conveyed along the motor nerves from the center in the spinal cord. This process, however, is complicated by the fact that when an afferent nerve is stimulated it will sometimes produce reflex dilatation and sometimes reflex constriction. This has been explained by different Physiologists in different ways. Some Physiologists think that it is due to variations taking place in the center, or centers, the result being dependent upon the condition of the center and also upon the time when the stimulation is communicated to the center, varying conditions of the center, therefore, producing varying results.

Other Physiologists, in more recent times, explain this fact more satisfactorily in connection with the pressor and the depressor fibers. The depressor fibers, as we saw, are dilator fibers, whereas the pressor fibers are constrictor nerves. We have already discussed the cardiac depressor which connects the heart with the center—the medulla producing on stimulation dilatation of the splanchnic, and other blood vessels, and a consequent fall in the blood pressure. It has been found that if a portion of the sciatic nerve is cooled by the application, for example, of ice, then by the application of a stimulation to the central end of this sciatic nerve, there is a fall in the blood pressure. If the sciatic nerve is divided, and before the regeneration of the nerve is completed, if stimulation is applied, there is dilatation produced, whereas, if the regeneration is completed, constriction follows, indicating the existence in the sciatic nerve of two kinds of fibers, the dilator and the constrictor fibers the depressor and the pressor fibers. If an animal is subjected to chloroform or ether, and the central end of the divided sciatic nerve be stimulated, the blood pressure rises without any corresponding increase in the action of the heart. After some time a fall in the blood pressure takes place, in some cases, even while the stimulation continues. Pressor fibers have been found in the laryngeal nerves, the trigenival nerve and the cervical sympathetic. This rise of pressure results from the constriction of the arteries in the abdominal region. It has been found that if the animal is placed under the influence of chloral, instead of chloroform, ethe or curare, a fall in the blood pressure takes place instead of the rise. This seems to indicate that the result depends upon the center rather than entirely upon the nerve fibers; whether tue action is accelerator or inhibitory. Thus the depressor nerve acts as an inhibitory, and the pressor nerve as an accelerator nerve fiber, in connection with the blood vessels conveying the afferent impulses of inhibition or acceleration to the center.

As we have seen, there are two kinds of vaso-motor fibers, the vaso-constrictor producing contraction of the vessels, and the vaso-dilator producing dilatation of the vessel. The question is asked in Physiology, "How does this action take place?" The only answer that Physiologists can gixe to this question would seem to be, that the fibers do not act directly upon the muscular walls of the vessels, and it is probable that the action takes place by an inhibitory action. In the vessel walls we find large numbers of ganglia. Out of these ganglia there pass nerve branches into the muscular walls. These local centers act, therefore, under the influence of the accelerator fibers and the inhibitory fibers.

Gaskell, on the other hand, thinks that these fibers exert a trophic influence, the constrictor fibers influencing Katabolism and the dilator fibers influencing the anabolism of the blood vessels. Blushing is a result of vaso-motor-action, certain emotions originate impulses in the brain which powerfully inhibit the vaso-motor center, governing the vascular region of the head, governed by the cervical sympathetic. The relaxation of the muscular walls of the vessels results, the arteries being distended and suffusion taking place. Sometimes pallor—the paleness of the skin, is also produced in the reverse way, that is, pallor is sometimes also the result of vaso-motor action. It results from the constriction of the arteries through the cervical sympathetic and the vaso motor center. The blood pressure is also influenced by respiratory action. Inspiration takes away the pressure from the external surface of the vessels allowing the large veins and arteries to expand; as the veins are more expansible during inspiration, the blood tends to collect in these large veins next the heart. causing, therefore, a fall of blood pressure in the aorta. In expiration, on the other hand, the reverse of this process takes place, the blood pressure being increased at the aorta. This, however, is not strictly scientific, because, during inspiration there are two moments or stages. During the first stage the blood pressure falls. During the second stage the blood pressure rises. This is due in part, at leaft, to vaso-motor action. During the second part, of inspiration certain influences are sent from the center, causing the contraction of the small vessels and producing a rise in the blood pressure in the arteries. During the 1st part of inspiration the cardio-inhibitory center acts, and the heart, as a result, beats more slowly. Thus, the vaso-motor influence, acts upon the blood vessel in connection with respiration, Some attempts have been made to specify and localize all the nerves in connection with the different regions of the body. This, however, is topographic rather than physiological and therefore, belongs to the field, not of Physiology, but of Anatomy.

SECTION XV—III. Branch of the Circulation. General Circulation, Its Mechanism, Including the Circulation of the Blood and the Circulation of the Lymph.

PRESSURE:—We have studied specially the organs of circulation and their Physiological bearing. There are still some points left that belong to circulation, not specially, but in general. The circulatory system, as we have said, may be ideally considered as a tubular arrangement. If the blood is regularly distributed under the same pressure, there will be an equilibrum in the circulation, and circulation would be impossible. When the pressure varies at any point, as in the case of the ventricular contraction the blood will be thrown out of that place with greater pressure to the part in the circulation with the lower pressure, and hence the circulation will be normally promoted.

If the heart action, on the other hand, is arrested, then the pressure is diminished. This diminution takes place gradually until the blood ceases altogether to circulate. Thus, beginning with the heart in its opening into the aorta, we have the point of the greatest pressure, the pressure gradually diminishing along the arterial system, the capillary system and the venous system until we come back again to the heart. Consequently the blood flow is from the heart through the arteries, capillaries and veins to the heart again. Each heart beat ejects as much blood into the arteries as returns into the heart from the veins and as the opening into the heart from the veins are more subject to dilatation than the openings of the arteries, the pressure in the arteries increases.

Artificial arrangements have been made by some Physiologists, as Weber and Hering, called the schema of circulation, consisting of a main pump representing the heartwith tubular attachments to represent the arteries and veins. It can be easilyshown in this way that if the pressure in the arteries and veins is equal, there can be no circulation, and also it has been proved that by increasing

the arterial pressure, the circulation is efficiently promoted through the whole circuit of the tube. Thus the circulation of the blood as a whole depends upon two facts: 1. The strength and rhythm of the heart beat. 2. The resistance that is set up in the capillaries which we have called peripheral resistance. This peripheral resistance increases the arterial blood pressure, and thus, as you notice from the increase of the arterial blood pressure there is a new force added onto the force in the heart, driving the blood out of the arteries toward the capillaries into the veins, thus promoting the circulation of the blood out of the arteries toward the capillaries into the veins, thus promoting the circulation of the blood. The main force in the circulation is the heart. Under this influence the blood circulates through the vessels, exerting a constant influence in the form of pressure at every point along the line of circulation, this pressure varying at the different points, being high in the arteries, greatly diminished toward the capillaries and being low when it reaches the veins, the blood flowing continuously from the high pressure to the low pressure through the capillaries which represent medium pressure.

If an artery, e. g., the carotid is ligatured in two places so as to leave an isolated portion, that isolated part can be divided, and a long canula open at the two ends can be fixed into the proximal end of the artery. If the ligature be removed and the canula be held upright the blood will rise to a certain height and remain there. If a vein, e. g., the jugular, be ligatured and then divided, and a tube be inserted in the distal portion, on removing the ligature the blood will rise in the tube but only a short height. This has been estimated in the case of the dog as varying from 155 centimeters in the aorta to 18 centimeters in the veins of the head, representing a variation in pressure of 8 or 9 : 1 in the case of the arteries and veins. In connection with this rough experiment we notice that the arterial blood is constantly moving up and down, the variation representing 1 or 2 centimeters, corresponding almost identically with the frequency of the breathing, whereas the smaller variations in the surface correspond with the heart-beat. On the other hand the venous blood is almost perfectly still and steady. From this we conclude that the arterial pressure varies with the respiratory movements of the chest and with the contractions and relaxations of the ventricles of the heart, producing the continuous movement of the blood through the capillaries; whereas the venous pressure is steady and maintains the even blood flow toward the heart. The first application of this arrangement to the arterial and venous blood pressure was by Hales in 1727. He took a long tube nine feet and one-fourth of an inch in diameter, provided with a stopcock connecting the tube with the crural artery of a horse, admitting the blood into the tube, and watching the vibrations of the blood in the tube at each heart-beat, the pressure being measured by the column of blood and the variations of pressure by the vibrations of the blood in the tube. This method, however, is unsatisfactory on account of the length of the tube required and the readiness of the blood to coagulate. In 1828 Poisenille devised the bent tube in the U shape and put mercury in the bend, a substance heavier and more movable than the blood. He also used means to prevent the clotting of the blood, securing a convenient arrangement for observation and measurement. This instrument was called Hæmadynamometer. The modern mercurial manometer is an improved form of this instrument. It consists of a glass tube bent in V shape, open at the two ends, held in position by a metallic frame-work. Mercury is placed in the vessel so as to occupy the bend. The one end fitted into the blood vessel is capped with a stop-cock. Before the blood is passed into the tube a solution is passed into the tube to prevent the blood from coagulating, e. g., carbonate of soda or magnesium sulphate. On account of the cardiac and respiratory changes this method was unsatisfactory, because the pressure could not be accurately read. Ludwig invented his self-registering manometer to get over this. He placed upon the mercurial surface in the distal limb, a small ivory float, bearing a light marking rod. Any change in the mercury caused the marker to rise or fall, with an arrangement for marking the change, by means of which cardiac and respiratory changes are graphically represented in carved lines upon a moving surface of the kymograph. The pressure represented upon this instrument is the mean blood pressure. Various attempts have been made to register the slighter changes by means of the spring kymograph which possesses the advantage of delicacy and accuracy. These instruments are valuable as showing the variations in individual beats with the changes in vibrations.

To secure a blood pressure tracing, an artery is laid open in an animal subjected to chloral. Thereafter two ligatures are applied so as to isolate a part. An incision is made into the artery, and a tube inserted in the vessel next the heart. The tube is filled with anti-coagulation solution, and connected by a rubber tube with the short limb of the manometer. The ligature is then taken off and the blood flows, acting upon the solution, and the mercury in the manometer pushing up the float which vibrates, and then records its movements. To discover the intra-vascular pressure at any moment, we must measure the height of the ordinate, a vertical line drawn from the curve recorded by the manometer to the abscissa, or horizontal base line, this latter representing the height of the column of mercury, under the influence of the atmosphere and the solution of carbonate. This number must be doubled in order to represent the actual blood pressure, because the mercury in the proximal limb sinks just the length the mercury rises in the distal limb. This enables us to represent the blood pressure in millimeters of mercury, varying in the different arteries and veins. If the canula be inserted in the large veins of the neck at the entrance into the thoracic cavity, there will be found a negative pressure representing a friction action from the inside of the vein. These facts indicate that blood pressure is, as we stated, dependent upon purely physical laws, being simply a movement of the blood within the tubular system, from a tube in which there is a high pressure to tubes of lower pressure. If the blood vessels are injured or cut, certain phenomena are noticed, e. g., in the case of an artery, the high pressure causes the blood to flow out like a jet, whereas, from a wounded vein the blood flows steady without any pulsation. This represents roughly the variation in pressure found in the arteries and veins.

From such experiments as these, certain conclusions have been reached in regard to the blood pressure. That conclusion varies in the case of arterial pressure, the capillary pressure and the venous pressure. (1) The arterial pressure. The arterial system, as we have seen, gradually increases its cross section area by the multiplication through division or sub-division of the minute vessels. This division and sub-division mark the transition from the minute arteries to the capillaries. Arising from this minute sub-division there is a strong force of resistance transmitted backwards according to the physical laws of fluid pressure, through the capillaries, through the minute arteries, and through the larger arteries toward the heart. This resistance originates in the capillaries, presenting a very strong resistance to the blood flow from the heart. This resistance is greatest, of course, in the capillaries and in the smaller vessels, gradually diminishing backward along the blood path until we reach the heart. This resistant force, therefore, meets the great force of the heart.

At the aortic opening into the heart the ventricular force throwing open the valve, drives out the blood from the ventricle into the arterial system with

an intermittent stream, this ventricular force meeting and over bearing the peripheral resistance that is sent up from the capillaries. The great pressure, therefore, in the arterial system is due to the interaction of the great force of the heart and the resistance that is sent up from the periphery. This high pressure in the arterial system maintains its uniformity, chiefly on account of the elasticity of the arterial walls. At each heart beat there is ejected from the heart into the arterial system a certain volume of blood. This volume of blood has to meet the resistance from the capillaries. This must be compensated for, by the discharge of blood from the arteries into the capillaries and at the same time the distension of the arterial walls, so as to provide for an accommodation of the volume of blood. As these successive blood ejections take place the aeterial walls yield before the peripheral resistance, the blood remaining in the arterial system, and thus increasing the blood pressure. This goes on until the limit is reached. At this point the walls are fully distended; they become hard and stiff. As a result of this the blood pressure is very high, and the successive blood ejections from the heart cause the pushing backward of the blood into the capillaries. Thus the normal condition of arterial pressure would represent the discharge of blood from the arteries during the ventricular diastole into the capillaries equal in volume to the amount of blood thrown out of the heart into the arteries at each ventricular beat. During each systole of the heart, the muscle of the heart actively performs a certain amount of work in producing a force to expand the arterial walls, for the purpose of accomodating the blood driven from the heart into these arteries and also assisting to sustain the capillary blood flow against the peripheral resistance. The force thus generated by the muscular activity of the heart is divided between the elastic arterial fibers in expansion and the capillaries which receive the blood supply from the arteries during the arterial recoil when the heart and the heart muscles are resting. At the commencement of the diastole the arterial recoil closes the arterial valves. During the systole of the heart on the other hand, the arterial walls are expanded before the volume of blood that is thrown into the arteries from the heart, and in this way the pressure of the blood is raised on account of the increase in the volume of blood.

During diastole the arterial walls recoil and the blood pressure falls on account of the increased quantity of blood thrown out of the arteries into the capillaries. Before this fall in the blood pressure becomes low, the systole of the heart or of the ventricles rather, takes place and the blood is again driven out of the ventricle into the aorta, raising, once more, the blood pressure. these different stages go on successively, preserving, in this way, the mean blood pressure that is normally found in connection with the arterial system. The arterial blood pressure is caused: 1st of all, by the blood driven out of the heart on the contraction of the ventricle 2. By the resistance that is met with in the minute vessels, known as the peripheral resistance; and 3. By the elasticity of the arterial walls. These are three causes of the arterial blood pressure. Thus the pressure of the blood is lessened gradually from the heart to the capillaries. It reaches its highest point in the case of the ventricle during systole, and its lowest point in the auricle during diastole, during which as we will find, there is often found a negative pressure in connection with the large veins and the auricles.

The arterial blood pressure varies, rising at the moment of the ventricular systole and falling at the moment of diastole, these variations being greater at the points nearer the heart. The mean pressure of the whole arterial system is to be distinguished from the mean blood pressure at any one point along the arterial blood path. The mean blood pressure of the arterial system is estimated by calculating the mean pressure at the different points along the arterial system and then striking an average between these different mean pressures. This mean blood pressure of the arterial system varies with the volume of blood found in the arterial system, for example; in plethora and in the case or transfusion, consequently lessening of the total arterial calibre will raise the mean blood pressure. The mean blood pressure increases with the force of the ventricular beat, so that the acceleration of the heart's action increases the mean blood pressure. If, on the other hand, the action of the heart is weakened, as in an anæmic condition, and in the case of the loss of blood by hemorrhage, of the mean blood pressure is lessened. In certain abnormal conditions, for example, in the case of fever, and in the case of hemorrhage and in phthisis, the pressure of the blood in the arterial system is always lessened; while in the case of lead poisoning, for example, or in the case of the injection of ergot and digitalis into the blood, or in the case of the induration in the arterial walls and in case of the abnormal enlargement of the heart there is an increase in the blood pressure, at least, in the arterial system.

2 CAPILLARY BLOOD PRESSURE.—In connection with the capillary blood flow, we have seen that it is uniform and free from rhythmic changes. The pressure, therefore, of the capillary system is low, as compared with the arterial system. As we have seen, the force that drives the blood into, and through the capillaries, is the force of the heart imparted to the arterial walls, manifested in the recoil or contraction of the arterial walls, following distension. While the heart is resting. the arterial walls recoil, the work being carried on by the force transmitted from the heart at the preceding systole. This force is to meet with, and overcome the capillary resistance. Thus the forces which produce the capillary circulation are, 1st of all, the heart force. 2nd. The elastic force of the arterial walls, and 3rd The peripheral resistance. The blood that flows intermittently from the heart on its entrance into the capillaries loses its pulsation, and also its high pressure. There is much less resistance to be overcome in the passage of the blood from the capillaries into the veins, than in the case of the entrance of the blood from the minute arteries into the capillaries. This resistance is constantly diminishing through the course of the capillary circulation. The force of the heart beat is also greatly lessened, much of the energy having passed into heat, and this heat having been exhausted in preserving the arterial blood pressure. Thus, a lessened force meeting with a lessened resistance, is what we find in the capillary circulation. The blood flow is, therefore, slow and steady, and the pressure is also low all through the capillary system. At the arterial recoil, as we saw before, there is a volume of blood thrown into the capillaries during the ventricular diastole, equal to the volume of blood displaced during the ventricular systole. In this way the arterial pulse, and changes due to cease respiratory influences altogether at, or about, the close of the arterial system, leaving the blood in a constant stream to issue through the capillaries, supplying the tissues; and then returning to the veins. Any condition that favors or assists the blood flow to a capillary region, will raise the capillary pressure; for example, distension of the small arteries opening into the capillaries, contraction of the small veins on the other hand, leading away from the capillaries, will have the same effect, increasing the blood pressure, preventing the volume of blood passing away from the capillaries into the veins. The position of the capillaries and their arrangement in that peculiar net work among the muscular fibers together with compression, or contraction of the muscles bearing upon the capillaries, will influence the capillary pressure.

3 VENOUS BLOOD PRESSURE:—The venous blood pressure is lower in the minute veins than in the capillaries, gradually diminishing, as we saw, toward the heart. In the larger veins at or near the heart the pressure ranges from a slight positive to a slight negative. This negative pressure depends largely upon respiratory action. This diminishing blood pressure in the veins arises from the same causes as the low blood pressure in the capillaries. It is the heart force transmitted along the arterial walls and through the capillaries, that forces the blood into the veins. There is still, as we have said, a certain amount of resistance in the venous circulation, although the resistance is gradually lessening all the way toward the heart. The elasticity of the walls of the veins is very slight, and hence the blood moves freely along the venous blood path with no greater internal pressure than the external atmospheric pressure. While the heart force is sufficient to drive the blood through the veins, there are certain forces which assist the blood through the venous circulation toward the heart. These forces are three in number. 1st of all, the aid rendered by the lungs in the venous circulation. 2d. The force of the muscles of inspiration, and third, the force that arises from the skeletal muscles.

(1) The lungs exert an influence upon the venous circulation. During inspiration and expiration, the two stages of respiration, the lungs are stretched, the lung fibers drawing on the ribs, the diaphragm, the heart and the other organs in the thoracic cavity. This distending force acts upon the heart during the ventricular diastole. This same drawing force generates in the superior and inferior vena cava suction force which affects the venous circulation. This suction action tends to draw blood without the thoracic cavity inside the chest. As we have seen there is a negative pressure always found in the veins close to the chest, this negative pressure giving place to a positive pressure farther away from the chest in the venous blood path. Thus the elastic traction of the lungs is constantly exerting a drawing influence upon the venous blood toward the heart. (2) This force of aspiration in connection with the lungs is materially aided by the muscles of inspiration which by their contractions strengthen the traction force of the lungs. At each dilatation of the chest there is a force generated which sucks the blood into the chest cavity, when contraction takes place this force is suspended so that the muscular force which draws upon the venous circulation is not constant but is marked by the successive inspirations.

(3) There is an influence exerted temporarily by the skeletal muscles. When these muscles contract, compression is brought to bear upon the veins in close proximity to these muscles, so that the blood, by this compression, is driven out of the veins, and the venous blood pressure is overcome. Here the valvular arrangement of the veins, together with the free anastomosis of the veins, prevents the blood from being driven away from the heart and causes the blood, always, to pass in the direction of the heart. Thus muscular compression may temporarily assist in promoting the venous circulation. This is not constant, but only temporary, because if the compression is continued for a length of time it would result in the destruction of the vein, or the obstruction of the circulation, not by causing the blood to pass away from the heart, but by destroying the vein, or veins in this region. The diminution in the blood pressure is so great that in the large veins near to the heart it is estimated that the pressure is only about one-twentieth part of the pressure in the arteries next to the heart. There are no great variations in the venous blood pressure, unless in those large veins close to the heart in which the pressure increases during the auricular contraction and diminishes during the auricular expansion. Great activity in the heart produces a lessened pressure, all through the venous circulation. Anæmic blood conditions for example, produce a diminution

of the venous blood pressure. Plethoric blood conditions produce an increase in the venous blood pressure; changes, also, in the normal position of the limbs affect the venous circulation. For example, the raising of the extremities promotes the venous circulation toward the heart. The downward inclination on the other hand, of the head, retards the venous circulation toward the heart In the case of deep breathing, the traction force of the lungs increases the negative pressure in the veins close to the heart. This negative pressure increasing backwards along the blood path at each deep inspiration. When the chest relaxes, the pressure is raised, causing the venous pulsations, which are simultaneous with the respirations. At every inspiration the blood is being sucked out of the veins and the veins diminish in size. During expiration, on the other hand, the veins increase in size on account of the volume of blood from the smaller veins. In close proximity to the chest there is always, therefore, a negative pressure. In very deep inspiration this negative pressure may be extended so far along the neck and the arms as to reach what is called "the point of danger."

This point of danger is so called because of the danger that arises in the case of the wounding of the vein, or its being cut in some way, resulting in the sucking of air into the veins, and its passage along with the blood into the heart which may result in sudden death, from the sudden entrance of the blood and the air into the heart. This danger point is so called by surgeons because of danger associated with operations in this region. Various attempts have been made to estimate the blood pressure at the different points along the blood path. This, however, varies so much in the different individuals, and in the different conditions of the same individual that no importance can be attached to the estimated results. It is to be noticed, however, that 1/3 of the blood may be taken out of the system without any effect upon the blood pressure. It is estimated that 2-5 of the blood withdrawn, will slightly lower the blood pressure, a considerable fall being noticed in connection with the removal of 1/2 of the blood. If 3/4 of the blood volume is removed, the pressure gradually falls until the heart ceases altogether to act. In the case of the depleted blood, the transfusion of a .75 per cent solution of sodium choloride will raise the blood pressure, and tend to restore the normal condition of the blood.

SECTION XVI.—Velocity of the Blood Circulation.

The speed of the blood is of considerable importance. Various instruments have been invented in order to discover what this speed is. If an artery is cut the blood issues from the artery with great velocity. The blood moves along the blood path with considerable speed, gradually diminishing from the heart along the arteries and through the capillaries and the veins. The measurements, however, are only approximate, and they cannot be taken as indicating the real, or accurate velocity of the blood. In the larger veins and arteries the measurement cannot be made directly. If it were possible to measure accurately the vessel calibre, and also the volume of blood that passes through it in any given time, then it would be a simple arithmetical circulation to determine the blood speed. This, however, is difficult to determine, chiefly because of the varying calibre of the vessels, and the varying resistance that the blood meets with in the blood flow. The Hæmadromometer of Volkmann consists of a V shaped glass tube, with stop corks and metal attachments. The blood was then allowed to pass through the tube, and as the length of the tube was known the time of making, the circuit of the tube could be easily noticed. The velocity in this case, is retarded by the artificial glass nature of the tube, and hence, the measurement is not even approximate. The best instrument that

has been invented is the stromuhr, or rheometer of Ludwig. This stromuhr consists of two glass bulbs, equal in capacity, connected together at the top by a common tube. At the bottom ends of the bulbs there are two tubes with two smaller canulæ at the end, for insertion into the ends of the vessels. The two bulbs are fixed upon two metal discs, these two discs being turned on the top of two other discs, on which they can rotate so that each bulb can be moved around, so as to be brought into connection with the two lower tubes in succession. The one bulb is filled with oil, and the other bulb with defibrinated blood.

An artery is then divided and the two canulæ are connected with the two ends of the divided artery. The blood rushes out of the artery through the canula into the bulb, throwing out the oil into the other bulb while the defibrinated blood is pushed by the oil out of the other bulb into the other end of the artery. The time is noticed during which the one bulb filled with oil is filled with blood the other being filled with oil at the same time. This represents the time in which the volume of blood equal to the size of the bulb passes through the artery. From this estimate, the velocity of the blood can be estimated. The experiment is continued by reversing the bulbs. In the experiment of Ludwig the bulb was able to hold five cubic centimeters. From the time of allowing the first five cubic centimeters of blood to enter into the tube until the moment when the last five cubic centimeters escapes from the artery into the tube, one hundred seconds elapsed, during which time five cubic centimeters of blood was received ten times into the tube from the arteries, all the blood, except the last five cubic centimeters of blood, being returned again at the other end of the artery into the circulation. Thus in one second five cubic centimeters of blood has flowed. Estimating the size of the canula he found that 159 m. m. of blood flowed in one second. In this way he estimated the amount of blood flowing in a given time and also the speed of the blood. This point is of considerable importance in the Physiology of circulation, because it enables us to calculate, at least approximately the duration of the circulation. One difficulty in this case, is that the stromuhr only gives the velocity of the blood during the experiment. In rapid changes of the velocity, another method has been used to determine the normal blood velocity. Vierordt, a German Physiologist, constructed the Haematachometer, in order to estimate the velocity by observing deviation. This instrument consists of a small metal box with parallel glass sides with a canula at each side, these two being connected, as before, to the ends of the divided artery. Inside the box there is suspended from the top a pendulum; the vibrations of this pendulum can be read on a graduated scale. When the blood is cut off from the instrument the pendulum hangs vertical, when the blood is permitted to flow through the canula and through the chamber, the pendulum is deflected. The velocity can be estimated from this deflection because the graduation upon the scale is based upon the speed of a fluid where velocity is known. It has been found that the velocity of the blood is subject to great variation. In the different arteries the velocity, for example, in the case of the carotid artery of the dog, is found to be 205 to 350 mm per second, in the crural artery of the dog 140 to 240 mm per second. Chauveau, who conducted a great number of experiments, found in the large arteries close to the heart during systole there was a velocity of 520 mm per second, whereas during diastole the velocity was 220 mm per second, and during rest 150 mm per second. The arterial velocity diminishes toward the capillaries from the heart.

The capillary velocity cannot be measured directly by any of these instruments. It can be measured, however, by the use of the micrometer used in connection with the microscope. Some Physiologists have measured the speed of the blood in the capillaries of the retina in their own eyes. It is found that the velocity in the case of the capillaries is very much less than the in case of the arteries. Weber estimates the velocity in the case of the web of the frog's foot at 51-100 mm. per second, and in the case of the mammalian capillaries, 8-10 mm. per second. Other Physiologists estimate that in the human subject there is a normal capillary velocity varying from 6-10 to 9-10 mm. per second. Volkmann states that in the human subject the veloc y of the blood in the aorta is 600 times the velocity of the blood in the capillaries, and the velocity of the minute arteries is 10 times the velocity of the capillaries. In the case of the veins the velocity is small in the minute veins leaving the capillaries, increasing gradually as the veins become larger, until in the larger veins close to the heart it is found to be from 200 to 225 mm. per second, for example, in the jugular vein of the dog and also of a horse; these are estimated 200 to 235 mm. per second. The venous velocity increases, therefore, from the capillaries to the heart. This acceleration in the venous velocity is due partly to the diminished resistance. Comparing the velocity of the blood with the blood pressure, there are certain conditions that we find to be noted. In the case of the arteries, the velocity and accompany each other, both in rising and in falling, both the velocity and the blood pressure gradually diminishing from the heart to the capillaries. In the capillaries the velocity and the blood pressure are low. In the veins, on the other hand, there is a low blood pressure, diminishing gradually all along the venous path, whereas, the speed is higher than we have had it in the capillaries, and it increases all the way toward the heart. There is no relation, therefore, between the velocity of the blood and the blood pressure, being in direct relation to one another in the case of the arteries and in the capillaries, and inverse in relation to one another throughout the venous blood path. The velocity in the capillaries is very slow, compared, at least, with the large veins and with the large arteries, whereas, the minute veins and the minute arteries have a greater velocity than that we find in the capillaries. This fact is of great physiological value, because in the capillaries the great function of supplying the tissues is performed, a certain volume of blood being required to do this, and that the blood must pass slowly in order to permit the blood entering into the tissues and to allow the blood interexchange.

The circulation of the blood requires that an equal volume of blood must pass any two points in the circulation, in equal periods of time except in cases of abnormal disturbance. This, of course, does not mean that the rate requires to be uniform in all the arteries, capillaries and veins, because the rapidity in one is compensated for a lower rate in the others. This is easily explained because the large arteries and veins are few in number and small in their cross-section area as compared with the small vessels and the minute capillaries. The cross-sectional area increases with the subdivision of the vessels. This sectional area, therefore, is gradually increasing from the heart to the capillaries; hence, the smaller the blood vessels, the larger is the blood path at that region, the widest path being in the most minute capillaries. Vierordt, a German Physiologist, states that the cross-section area of the capillaries is eight hundred times that of the arteries at the root of the aorta, and four hundred times that of the veins at the venous orifices. Thus the venous circulation is much greater in calibre, than the arterial system. The arterial and the venous cones lie with their narrow ends toward the heart, connected together at the two bases by the capillaries. An equal volume of blood passes in the same, or equal periods of time, any two points

in the blood path, so that in the narrow path the blood must flow very rapidly, and, in the wider path, more slowly. The velocity, therefore, diminishes on account of the widening of the blood path toward the capillaries, causing the velocity to be lowest in these capillaries where the blood path is the widest. In the venous blood path, the gradual narrowing of the path toward heart causes the increase of the speed, and the fall in blood pressure, the speed being so much lower in the venous system, because the venous blood path is so much larger than the arterial blood path. The blood flows, therefore, much more slowly into the right auricle, than it moves out of the left ventricle, because the path is wider, although the volume is about the same. The reason of this is, the calibre is very much larger at the venous orifices. This corresponds with what we have found in connection with the heart, that the blood pours in during the long auricular diastole, and leaves during the short ventricular systole. It is found, therefore, from this standpoint, that the velocity of the blood flow depends upon the width of the path, being greatest at the aorta, diminishing toward the capillaries and then increasing again toward the heart in the venous system. Resistance in the capillaries plays only a very small part in determining the velocity, at least in the capillaries, but the increased sectional area is the element which determines the velocity all the way around the blood path. The ventricular force produces the blood flow through the entire circulation, generating the force of the arterial walls, and thus producing a force sufficient to keep the blood in active circulation during diastole, as well as systole. Thus we conclude: 1st of all, the speed of the blood is in inverse proportion to the calibre of the vessels measured in sectional areas. 2nd. At each systole the rapidity of the blood flow is increased in the large arteries close to the heart. 3d. The rapidity is constant in the small arteries, capillaries and small veins. 4th. The speed is increased in the veins toward the heart. 5th. In the large arteries the influences of the inspiration retard the speed while expiration increases it. 6th. In the large veins the influence of respiration and the suction force of the heart causes an increase of the velocity of the blood.

Time Occupied by the Entire Circulation.—The width of the blood path, as we have said, determines the rapidity, thus regulating the slow movement where the blood requires longer time to perform its functions in the tissues, and the more rapid movement where the blood simply passes along an intermediate path. In this way the red corpuscles are found to spend a large portion of time in the capillaries where these corpuscles are brought into active connection with the tissues.

It is important from the Physiological standpoint to distinguish between the blood rate and the time taken by a corpuscle in making the circuit of the blood path from the left ventricle to the left ventricle again. Duration is considered in respect to the single corpuscle. The time has been estimated approximately, during which, for example, certain substances pass from the jugular vein on the one side to the jugular vein on the other side. Hering injected, some drops of a two per cent solution of ferrocyanide of potassium, examining the blood on the other side every five seconds; testing it, on the other side, with perchloride of iron so that when the ferrocyanide appears on the other side there is a formation of Prussian blue. Various experiments of this and of a similar nature have led the Physiologists to conclude that the duration of the circulation is approximately, in the horse, for example, thirty-one and a half seconds, in the dog, sixteen and a half seconds and in man about twenty-five seconds. Vierordt, says, that the time of the entire circulation corresponds with the time occupied by twenty-seven or thirty heart beats. If we take, for example, the amount of blood in the body of a person weighing 140 pounds as about 5,632 grams. This would represent 5,322 cubic centimeters. Each heart beat drives out 172 cubic centimeters from the heart into the aorta, giving almost exactly thirty heart beats as the period during which the entire blood goes around circulation. Taking the pulse at its normal seventy-two, this would give us twenty-five seconds as the period or duration of the entire circulation.

CHANGE IN THE SIZE OF ORGANS:—Mosso has invented an instrument, the Plethysmograph, for the purpose of marking the changes in volume. It has been found by the use of this instrument that the size of an organ depends upon the blood supply in it. In the organ the volume is found to change with each heart beat, being enlarged by blood forced into it and diminished when the muscular capillaries are emptied into the veins. The tracings that have been made by this instrument correspond very much with the pulse tracings, and also with respiration indulations. The exercise of a limb lessens the volume on account of the increase of the blood flow out of the capillaries into the veins, although this is partly due to the increase of the lymph. Similarly, mental strain, brain work and sleep produce a lessening of the volume of organs. The blood is so distributed through the body that each organ receives the necessary supply according to its requirements. The activity of an organ determines the blood to it. For example, the activity of the mucous membrane of the stomach or the increase of the muscular exercise as of the limbs, determine the blood flow into these organs. There are, however, some organs whose continuous activity determines a constant supply of blood to these organs; for example, the heart, the nerve centers in the medulla and the respiratory muscles. These organs seldom if ever vary in the blood supply found in the case of normal activity. Changes in quantity are compensated for, and this compensation leads to the accurate distribution of the blood through the entire body. For example, in the case of hemorrhage or the artificial withdrawal of blood where the loss does not exceed three per cent of the body weight the loss is very quickly made up. This restoration takes place too quickly to suppose that it is due to the withdrawal of fluid from the lymph. It is probably due as most Physiologists recognize, to vaso-motor action increasing the peripheral resistance and thus sending the blood out of the capillaries into the general circulation. If the loss exceeds three per cent of the body weight, the loss of blood seems to diminish the force of vaso-motor influence, thus preventing the rapid restoration of equilibrium. If blood, on the other hand, be injected into the circulation, no results are noticeable, if the vaso-motor center is intact. But if the spinal cord be severed, there follows after the injection of blood a rise in the blood pressure. This indicates the capacity of the vessel to hold a larger quantity of blood than that normally present in the circulation, the extra blood being contained in the capillaries and the small veins. When the quantity of blood is increased there is a diminution of the peripheral resistance by the activity of the dilator nerves so that the blood pressure remains normal, thus the increase or the diminution of blood does not materially affect the circulation, unless it is dangerously large on either side, that is in diminution or increase.

SECTION XVII.—The Movements of the Lymph.

The spaces in connection with the connective tissue of the body constitute the origins of the lymphatic system. Certain constituent elements

of the blood plasma ooze through the vessel walls into those spaces. From these spaces there is a constant flow of the lymph through the lymph capillaries into the larger lymphatic vessels through the thoracic duct and the great lymphatic trunk into the blood circulation. The lymph, first of all, is presented in those inter-spaces between the tissues, those inter-spaces being in constant communication with one another, and also with the small lymphatics, which, as they pass to the larger lymphatics assume the form of lymphatic veins. Those lymphatic veins have delicate walls and are arranged with a large number of semilunar valves with dilatation in the lymphatic vessels above the valves. These valves always open away from the inter-spaces and thus render efficient assistance to the lymph flow in its forward movements from the inter-spaces toward the larger lymphatic vessels. The smaller lymphatics are joined together in the formation of larger lymphatics. These larger lymphatics being all united together with the two main lymphatic trunks, the thoracic duct and the right lymphatic duct. The right lymphatic duct is short, being the terminal of the lymphatics of only a small portion of the lymphatic system. All the other lymphatics terminate in the thoracic duct. The thoracic duct runs along the entire extent of the thoracic cavity. These two main ducts have very delicate walls, also, a valvular arrangement so as to promote the movement of the lymph away from the smaller lymphatics and to prevent lymphatic regurgitation. The two main ducts terminate on the two sides of the neck where, at least in the human subject, the duct cavity unites with the junction of the subclavian and the internal jugular veins, in the formation of the innominate vein. At this junction of the ducts with the veins there is a valvular arrangement permitting of the passage of the lymph into the veins but preventing the passage of the blood from the veins into the duct. Throughout the serous cavities of the body there are, also, found the beginnings and terminals of the lymphatic systems, these serous cavities being large surfaces in the lymphatic circulation. Here and there in the course of this lymphatic circulation there are found lymphatic ganglia constituting the lymphatic glands through which the smaller lymphatics pass.

These glands present, at least from the standpoint of the circulation, a resistance very similar to the peripheral resistence found in the capillaries in connection with the blood circulation. Thus, the analogy between the lymph in the lymphatic circulation and the blood in the blood circulation is almost complete. The lymph circulates from the lymph spaces, through the lymphatic vessels, and the lymphatic ducts, terminating in the venous junction in the neck, and thus is brought into close connection with the blood system. The tissues of the body are nourished by the fluid that is transuded through the capillary walls. Part of this fluid passes into the living tissue, and the balance is carried away in the form of waste. In all the tissues of the body that receive blood, the lymphatics are found very abundant, particularly in the region of the arteries and of the veins. The lymph does not pass directly into the blood, but through the lymphatic glands. The lymphatic vessels contain delicate walls from 2-10 to 6-10 mm in diameter. These delicate walls of the lymph vessels consist of three coats. 1st. of all, the intima of endothelium and elastic fibers. 2nd. The media of transverse muscular fibers and also elastic fibers. 3d. Adventitia consists of connective tissue, intercalated by elastic tissues and smooth muscular fibers. The minute lymphatic vessels consist entirely of endothelium cells. These endothelium cells being formed into capillary bundles, all of them opening toward the periphery. The fluid which has been exuded from the blood vessels, passes into these minute lymphatic vessels by the process of osmosis or as some Physiologists think, through the lymphatic openings that are embedded in the tissues. According to some Physiologists, the theory of osmosis is not correct; they say that in the very minute lymphatic vessels there are delicate mouths, or openings which pass down into the lymphatic spaces, and each one of these openings represent a mouth through which the lymph passes out of the spaces into the minute capillaries.

Along the lymphatic path there are, as we have seen, lymphatic glands, small, rounded bodies of varying sizes, representing the collection of the lymphatic vessels at certain points along the lymph path. On the one side of these glands there is a small fissure in which the lymph vessels are found to arise. The gland is covered with a sheath of connective tissue, and the gland is divided into a number of sections, forming a dense plexus in which there are embedded the smaller lymphatics, and from which arise the larger lymphatics. These lymphatic glands are very freely supplied with blood vessels, either on the surface, or in the fissure.

Nerves, also find connection in the gland, in what way this connection is established it is not known. The capillary system brings the blood to the different tissues and as the capillary walls are delicate there is a free osmosis through these walls under the pressure of blood in the capillaries. Under this filtration process the water in the blood together with the saline substances in solution pass freely without carrying any of the albuminous substances along. It is thus laden with oxygen which is of value in the process of respiration and nutrition for the upbuilding of the tissues. After the tissues take up what is necessary for them the lymphatics collect the excess carrying it off in the lymphatic system. Where there is a large excess of this fluid transuded from the blood, too large to be appropriated by the tissues and to be taken up by the lymphatics we have a condition superinduced in the tissues of the body to which the name of œdema is applied. This same condition may be produced by the constriction or the obstruction of the lymphatic circulation, producing a swollen condition of the tissues– for example, in dropsical conditions. Thus, the lymph originates partly from the blood and partly from the tissues of the body. The lymph passing through the glands, washing out these glands and in this way often collecting in the lymph stream a large number of lymph corpuscles. The lymph, itself, is a clear, colorless or pale yellowish fluid, transparent or slightly opalescent coagulating very quickly under the influence of fibrin, this fibrin being the same as the fibrin that we find in connection with the blood. The lymph clotting being almost the same as blood clotting. The chemical composition of lymph varies very much, resembling the blood plasma except in one particular, its poverty of albumin. The specific gravity of the lymph is about 1017 varying to about 1025. When the lymph is microscopically examined it is found to contain a large number of lymph corpuscles and sometimes a few red corpuscles. These corpuscles are smaller than the white blood corpuscles, although some Physiologists have said they are identical. The lymph corpuscles are globular in shape, consisting of a large nucleus with a narrow granular margin varying in size from 5 to 15 micra. In the lymph there is found about 1-10 per cent of fibrin the ferment of the blood and the ferment of the lymph. As the lymph is transuded from various vessels and tissues of the body it varies very much in its character as it is found in the different parts of the body.

The solid matter is usually much less than that found in the blood, being not more than 5 or 6 per cent. of the solid matter. The venous blood is

found to be much richer in solid matter, than the arterial blood, because the fluid part has been partly transferred into the lymph. There is found in the lymph varying percentages of albumen, smaller quantities of extractives a small proportion of salts together with slight traces of fatty substances with a large percentage of CO_2 and only a small trace of oxygen. In a hundred parts of human lymph it is estimated there are 95 per cent. of water and 5 per cent. of solid matter. Of this 5 per cent. of solid matter, 4 1-10 per cent. of albumen; 5-10 per cent. of the salts, 3-10 of the extractives and 1-10 the fibrin, with a trace of fat. In the lymph spaces, capillaries and minute vessels there is a large percentage of water, whereas, in the larger lymphatics there is an increasing percentage of solid, the number of corpuscles increasing in the passage through the lymphatic glands. The pericardial and peritoneal fluids are also lymph, containing at times less and at times more solid matter than the normal lymph, otherwise presenting the normal characteristics in corpuscles and composition. The amount of lymph varies from time to time in different regions. Active exercise increases the flow of lymph, as also the hanging of the hand, the swollen appearance resulting from the increase in lymph and blood in the veins. Similarly the skin and tissues ma ybecome shrunken on account of the absence of the lymph. In 24 hours it is estimated that lymph is formed equal to 1-10 of the body weight. The lymph is so important in sufficient quantities that death very soon supervenes if the lymph loss becomes excessive, so that its existence in normal condition and its circulation are necessary for life. In man there are said to be no lymph hearts, such as have been found in connection with the frog, these lymph hearts in the frog giving rise to certain rhthmical contractions. According to some physiologists, there do exist lymph hearts in the human subject. Where these lymph hearts exist they consist of small dilatations with striated muscle fibres in the walls. Where they exist their pulsation is not in any way connected with the heart beat. In connection with the lymphatics unstriped muscle fibers are found in the walls and it is said that pulsations take place in connection with the muscle fibres as it is more probable that these fibres regulate the calibre of the lymphatics under the influence of the nervous system.

The lymph flows with a great rapidity through the thoracic duct into which the lymph is continuously being poured from the smaller lymph vessels and also from the lymph spaces. The forward movement of the lymph depends upon a number of circumstances. The lymph moves, as we have seen before, from the roots of the vessels toward their trunks. This movement is slow as compared with the movements of the blood; hence, it is estimated by the Physiologists that in the lymphatics of the neck, for example, the lymph flow represents 4mm. per second. We have four circumstances or conditions that influence the movement of the lymph, these we will specify: 1st of all, the valvular arrangement of the lymphatic system, as in the case of the veins, the lymphatic vessels are materially influenced by the pressure of the skeletal muscles. The valves of the lymphatic system prevent the lymph from flowing backward, always forcing the lymph forward toward the venous system and preventing the regurgitation of the lymph. In the case of a divided lymphatic vessel the simple motion of bending or straightening a limb, produces a profuse discharge of the lymph, this discharge being due to the pressure exerted by the muscles. In this way muscular movements tend to increase all the time the lymph movement, along the lymphatic path. The entrance from the thoracic duct into the venous system is protected also by a valve so that the lymph must flow freely in one direction from the lymphatic system into the venous circulation and the blood cannot flow from the venous system into the lymphatic system. 2d. Lymph pressure. The pressure of the blood in the capillaries and in the smaller vessels is very much larger than in the larger arteries, producing, as we saw, the blood flow from the capillary system always toward the heart. In the lymph spaces the lymph also is subject to considerable pressure, along the lymph path, also, the lymph flow in effectively sustained by the valves, as we have seen, which keep it up in one direction. In addition to this, at the close of the lymphatic system in close proximity to the venous system the pressure always varies from a slight positive to a slight negative. In the lymph spaces where lymph originates, the pressure is estimated about one half of the blood pressure in the capillaries; that is from 12 to 27 mm. of mercury. Along the lymph path there is, also, a resistance continuously met with, causing the lymph to accumulate in the lymph spaces of the tissues. This accumulation under the influence of resistance being balanced normally by the muscular activity of pressure of the muscles causing the steady onward flow of the lymph along the lymphatic path. On account of the difference in the pressure, between the blood and the lymph, in the capillary system, exudation takes place from the blood to the lymph spaces.

This pressure which causes the transudation of blood from the blood into the lymph spaces marks the highest point in the lymph pressure, determining, as we have said, the origin of the lymph current away from the lymph spaces that are found in the tissues toward a lower pressure, which is found at the junction of the lymphatic and the venous systems. This difference in pressure at the origin, and at the close of the lymphatic current always determines the lymph flow in the one direction toward the venous system. 3d. The Influence of Respiration. At every inspiration the pressure in the large veins near to the heart becomes negative, sucking, as we have seen, the venous blood, always toward the heart. Side by side, with this suction action that we find in the venous system, we find the suction force of inspiration, also pulling the lymph from the openings of the thoracic duct and the right lymphatic duct into the venous system. The thoracic duct lies inside the thoracic cavity so that at each inspiration the duct becomes somewhat expanded, setting up in this way, a certain suction action reaching backward to the lymphatic vessels that are outside the thoracic cavity, and always tending to pull the lymph, 1st of all, toward the great duct, and then from the great duct into the venous circulation. 4th. In addition to these three influences we have, also, two other influences upon which Physiologists, however, are not fully agreed. These two influences are, (1st.) The pressure arising from the osmosis. (2d.) The pressure arising from the muscular contractions of the lymphatic walls. The blood pressure in the capillaries throws out the fluid as we have seen, into the lymph spaces, thus originating, at least, the lymph flow from these lymph spaces. The increase of blood pressure increases at the same time and the decrease of the blood pressure decreases at the same time the current of the lymph, so that the flow of the lymph depends largely, if not altogether, on this origin in the pressure of the flow in the capillaries. The walls of the lymph vessels, as we said before, are muscular, especially at the valvular regions. These dilated regions are said to contract after the same fashion as the heart during systole. This adding to the force which drives the lymph always onward from the lymph spaces to the larger lymph vessels. These movements, however, in the human subject, are only ideals,

because so far, no experiments have been made to indicate that there are such lymph hearts.

These lymph hearts, as we said before, do exist in the frog, but whether they exist in the human subject or not is simply a matter of theory. From the standpoint of theory the pulsation of these lymph hearts seems to present a possible explanation of a certain amount of pressure brought to bear upon the lymph in its onward movement.

The combination of these influences tends to produce a steady lymph flow toward the larger duct, even against the force of gravity, this flow is steadily maintained from the lower limbs; especially by the valvular arrangement, preventing a backward flow. It is also supposed by some Physiologists that from the analogy of the blood circulation that the nervous system exercises an immediate influence on the distribution of the lymph and in its circulation through the lymphatic system. This, however, has not yet been demonstrated by physiological experiments. In the passage from the blood to the lymph there are two characteristic stages. (1st.) The passage from the blood to the lymph spaces and (2d) The passage from the lymph spaces to the lymph vessels. These lymph vessels are not always closely connected with the blood vessels. Hence, this has raised a difficulty in Physiology to explain the flow of the lymph out of the spaces into the lymph capillaries. Attempts have been made by some Physiologists to apply the principles of diffusion and of filtration to the passage of the lymph from the lymph spaces into the lymph vessels. The passage, however, through the vessel wall cannot be explained either by principle of diffusion or by the principle of filtration. The explanation becomes more difficult when we consider that a double passage takes place between the blood and the lymph spaces and between the lymph spaces and the blood, indicating that in addition to a purely physical principle of diffusion or filtration we must always take account of the Physiological condition of the vessel walls. According to some Physiologists the same process takes place in the passage of the lymph from the lymph spaces to the lymph capillaries as takes place in the passage of the fluid from the blood into the lymph spaces. This, however, is incorrect, because there are openings at certain points along the lymph capillaries into the lymph spaces forming a direct passage from the lymph spaces into the capillaries, whereas, there are no openings between the blood and the lymph spaces unless through the walls, as we saw before, when the fluid and sometimes the white corpuscles and sometimes the red corpuscles press their way through between the margins of the cells which line the walls of these blood vessels.

The quantity of lymph varies, the tissues demanding in certain circumstances more lymph, although it never normally exceeds a certain definite quantity. This limit may be exceeded in pathological conditions resulting in œdema. Oedema may be produced in one of two ways: an excessive transudation from the blood into the lymph spaces or by some obstruction to the transudation from the lymph spaces to the lymph capillaries. In the latter case an obstruction does not materially affect the lymph-flow as the anastomosis of the lymph vessels like the venous anastomosis opens up a free passage for the lymph in another path toward the ducts. Thus the real cause of œdematous condition is excessive transudation. These, however, belong to the field of pathology. The importance of the lymph circulation is evident from the close relation it bears to the blood circulation, from the amount of fluid that daily passes through the lymph circulation, and from the dangerous effects resulting from the excessive accumulation of lymph.

The blood circulation depends upon certain factors, all of which vary more or less, the heart-beat, the peripheral resistance, the length of the vessels and their calibre, the elasticity of the walls and the valvular mechanism. These under the force of muscular contraction and relaxation and under the influence of the nervous system keep the blood in proportional distribution and normal circulation in the body. The quantity and quality of the blood, also exercise an influence on the circulation. It seems remarkable that the heart should go on continuously resisting temporary irregularities and overcoming temporary obstructions, and at last without almost any notice cease to beat and suspend life. Each heart-beat, however, involves an effort, and the effort is one to sustain life against the odds presented by all the resistances of the system. Thus the maintenance of life through the circulation of the blood with the analogous circulation of the lymph represents the most important factor in life. When we add to this the influence exerted by the nervous system upon the circulation keeping up the tonic condition of the vessels, and maintaining the distribution and circulation of the blood, we have the foundation factors of the life in the human system. Along the entire blood path, then move influences that during life are constantly playing a most important part in the upbuilding, general development and continued existence of the human life. If the statement of Dr. A. T. Still is correct, and we accept it with all the force of his life study behind it, "that a natural flow of blood is health; and that disease is the effect of a local or general disturbance of blood," then you can understand and appreciate the reasons that have led us to devote such a large portion of our time to the exhaustive study of the blood and the circulation, and at the same time feel that when we have completely mastered this subject, we have laid a solid physiological foundation for the rest of physiology and for the whole science of Osteopathy.

CHAPTER IV. RESPIRATION.

SECTION I.—The General Statement in Regard to Respiration.

Respiration is essentially an interchange between the gases of the organism and the gases of the medium in which the organism lives. Oxygen is essential to the life of every tissue, whereas carbon-dioxide is destructive of organic life. The simplest organism, such as the amoeba and the infusoria when deprived of oxygen or placed in a medium that is over-charged with carbon-dioxide, become exposed to death, so that for the sustenance of these simplest forms of life, fresh oxygen must be brought into the system and the carbon-dioxide must be removed from time to time in order to the preservation of the organic life.

This interchange of gases takes place, constantly in all forms of animal life, from the lowest to the highest. In the lower organisms in which the structure is very simple and in which the life is very much less complicated, no complex mechanism is necessary, because these simple organisms are either directly plunged into the fluid upon which they live or have certain passages throughout their system in which the fluid passes to all the different parts of the organism. In the higher organisms in which the fluid circulates throughout the system, arrangements are necessary for an interchange between the gases that are found in the fluid and the gases of the surrounding substance of the bodily organs; for example, the tracheæ that are found

distributed throughout the bodies of insects, the gills that are found in the fishes. By this mechanism the air is brought into close relation with the fluid and thus introduced into the organic system, causes an interchange. In the higher forms of life we have differentiated organisms in the form of sacs with tubes communicating with the surrounding medium, the blood vessels lining the walls of this medium and furnishing the means of interchange between the internal and the external gases.

This sac, which is found very small in the lower animals, passes into the complicated honey-combed lung, the structure of which is of such a nature that cells, with minute capillaries, present a large surface in which this gaseous interchange is constantly taking place. In these highest forms of animal life there is a definite mechanism involving muscular movements and nervous action, for the purpose of introducing into, distributing in, and expelling the air of the gases from the organs of respiration. Thus the process of respiration becomes more complex as we rise in the scale of animal life. In amœbic life, the amœba lives in the fluid saturated with gases. In the higher forms of life, definite tracts exist for the admission and for the distribution of the gases, either directly, or as in the case of the fishes, by the admission of water containing in this case, the gases. In the still higher forms of life, as for example—in the frog, there is a process of swallowing the air, by which the air is forced into the air sacs, while in the case of man we have a complex automatic action of muscles and of nerves, playing such a very important part in the process of respiration. The object of respiration is two-fold. 1st. of all, to take in a fresh supply of oxygen, such as is found necessary for the process of oxidation in the human body, and 2nd. to expell the carbon dioxide formed within the body. In the complex organisms, such as the human body, the phenomena of respiration may be divided into two parts. 1st. There is an interchange of gases which takes place between the blood and the tissues. This is sometimes spoken of as internal or inner respiration. 2d. In order that this process may go on successfully, there must also be an interchange between the gases in the blood and the gases of the surrounding atmosphere. In this way external air is introduced into the air cells of the respiratory organs. This interchange is called the external, or the outer respiratory process between the blood and the external atmosphere. In the human subject this process is carried on almost entirely in connection with the lungs, hence, this process of respiration is sometimes called pulmonary respiration. 3d. In addition to these there is a subsidiary respiration carried on in connection with the skin. This is called cutaneous respiration.

There is also a respiration carried on in connection with the intestines called intestinal respiration. There are also some changes that take place in connection with some other organs, but these are of minor importance. Both of these inter-changes are, in the main, physical processes rather than phsyiological, because they are due to the mutual diffusion of the gases and depend but slightly upon the epithelial cells that cover the surfaces through which the passage of these gases takes place. The respiratory apparatus, therefore, in the human subject, consists of the following mechanisms: 1st. The lungs with a large number of air vesicls and air cells connected together and in close connection with a dense plexus of blood vessels. 2nd The air passages leading to the lungs and communicating with the lungs. The air passages include the nose, the pharynx, the larnyx, the trachea and the bronchi, including the bronchioles. 3d. The thorax and the muscular mechanisms connected with it, by which the lungs are filled and emptied, and 4th. The nervous mechanism of respiration. 5th, and last, the subsidery function —discharged by the skin and by the intestines in the respiratory process.

SECTION II. The Respiratory Apparatus.

The larnyx is made up of several parts, forming a cartilaginous framework, the different parts of which are movable upon each other by means of certain muscles. There are three single cartilages: the thyroid, the cricoid and the epiglottis. There are three pairs of cartilages: the arytenoid and the cartilages of Santorini and of Wrisberg. The thyroid consists of two lateral plates which meet one another at an angle anteriorly forming the prominence known as Adam's apple and leaving between them posteriorly a wide open space. The cricoid cartilage placed between the thyroid, and trachea is shaped like a signet ring, the deep part being behind, the seal projecting upward. On the lateral part of the upper border of this seal there is on each side an open surface for articulation. The external surface of the cartilage is smooth in front but at the sides it becomes irregular and furnishes attachment to the crico-thyroid muscles and to the superior constrictors of the pharynx. The epiglottis is a plate of yellow elastic cartilage shaped like a leaf, the narrower lower part being attached to the deep surface of the thyroid cartilage in the middle line, the broad upper part projecting upward at the root of the tongue. In swallowing, this part is pushed downward and backward so as to be horizontally over the superior aperture of the larynx. During respiration its direction is vertically upward, the free surface curving forward toward the base of the tongue. It is covered with mucous membrane, a continuation of the lining of the pharynx and two folds of epiglottidean ligaments, underneath the mucous membrane being a number of small pits in which are lodged small glands opening on the mucous surface.

The mucous membrane of the larynx is thin and pale and has numerous glands opening on the surface, except at the upper and especially at the upper lateral part and over the true vocal cords, where it is squamous, the epithelium being ciliated and columnar. The mucous membrane is continuous below with that of the trachea; as it ascends it turns inward to pass over the edges of the true vocal chords. Again it passes outwards and then ascends a short distance on each side forming a fold, each fold overhanging the true vocal chord, and forming the false vocal chords. The true vocal chords are bands of elastic tissue covered with mucous membrane, this mucous membrane being very thin and adhering closely to the elastic bands. The false vocal chords are simply folds of mucous membrane. The superior aperture of the larynx is triangular in shape, wide in front where it is bounded by the epiglottis, and narrow behind where it is limited by the tops of the arytenoid cartilages and the cornicula laryngis. The sides of the superior aperture are formed by the aryteno-epiglottidean folds which slope downwards and backwards from the sides of the epiglottis. The superior aperture is closed during swallowing by the bending backwards over it of the epiglottis on the deep surface of which in the middle line is the cushion of the epiglottis by which the accurate closure of the epiglottis is secured. The larynx is abundantly supplied with blood vessels constituting a plexus in the sub-mucous coat, out of which arise a large number of delicate capillaries extending down beneath the epithelium. In addition there are two plexuses of lymphatic vessels, the one very delicate underneath the epithelium and the other less delicate underneath the blood capillaries. The nerves terminating in terminals pass through small glanglionic centers, forming connections with the nerve fibers entering the pharynx.

The Trachea.—The trachea or the wind-pipe as it is sometimes called is cartilaginous and membranous tube. It passes downward in the middle line from the cricoid cartilage about 4 ½ inches and then bifurcates to form the two bronchi, one for each lung, the division taking place about the level of the upper border of the 4th dorsal vertebra. The diameter of the trachea is from ¾ of an inch to 1 inch. In front and at the side the trachea is firm and resistant, this resistance being due to the presence of the transverse bands of cartilage. Those transverse bands of cartilage form imperfect rings; the deficiency in those rings being behind where there is found a narrow compressible membranous portion of the trachea. Those imperfect rings are from 16 to 20 in number along the course of the trachea and sometimes they present a bifurcated appearance. Those rings are joined together by a coat which contains a medium proportion of elastic fibers. On the deep surfaces of this fibrous coating there are also found fibers of unstriped muscles, these fibers being arranged transversely. Within that fibrous coat is the sub-mucous coat in which are found a number of small mucous glands. The bronchi correspond in structure with the trachea. The right bronchus is wider, shorter and more nearly horizontal than the left bronchus. The bronchi entering into the lungs branch again and again forming finer and more delicate bronchioles, each of which ends in a dilatation; this dilatation being called the infundibulum. Changes take place ih the structure of the air tubes, as by this repeated process of branching they become narrower until they terminate in the infundibulum. The fibrous coating of these branches become thinner and thinner as the branch becomes smaller, and very distinct bundles of longitudinal yellow elastic fibers are found developing. The cartilage is found in small plates so arranged that together they completely surround the tube, making it quite cylindrical in shape. These plates of cartilage gradually become smaller and in the minute capillary bronchiole tubes they have entirely disappeared. The transverse muscular fibers form a laver all around about the inside of the tube inside of the cartilage, in the very finest tubes the muscle also, has entirely disappeared. The mucous membrane also gradually becomes thinner and more delicate as the tubes become smaller, but it still retains its columnar ciliated epithelium until just before the tube expands into the infundibulum, where we have patches of squamous epithelium.

Each of these finer bronchioles presents near to its termination, small recesses leading out from it, called the air cells. The tube ends in an inversely funnel-shaped expansion, known as the infundibulum. This infundibulum consists of a portion of the expanded tube, into which there open a number of air cells. These air cells have a wall of elastic tissue, lined by an epithelium of large, thin, flat cells, with smaller flat cells lying between those cells. Beneath this epithelium there is an extremely dense network of capillaries. The septa, between the adjacent air cells, are composed of a double layer of epithelium. Between these layers there is a single layer of capillaries, the blood in these capillaries being exposed to the action of the air on each side. The lungs are made up of bronchial tubes ending in the infundibulum, held together by connective tissue, which contains some pigmented corpuscles, and in which we find running blood vessels, nerves and lymphatics. The infundibula, or ultimate lobules, are there joined together into larger lobules, the outlines of whlch can be distinguished on the surface, and these lobules may be dissected from one another in the foetal lung. The lung surface proper, is divided by connective tissue into a large number of small lobules. The connective tissue between the lobulees is continuous, with a thin layer of connective tissue, containing numbers of elastic fibers immediately below the pulmonary pleura. The inter-lobular connective tissue is highly developed in the case of children. The right lung is the larger, the broader, and the shorter of the two. The blood for the nourishment of the lung substance reaches the lung by the bronchial artery, and is returned by the bronchial vein. Branching out from this bronchial artery, we find minute vessels extending along the whole course of the bronchi, the bronchioles, the air vescicles and the infundibula, forming capillary plexuses, beneath the epithelium. The minute veins arise around the sides of the air cells, running along the sides of the air cells and then uniting together to form larger vessels pouring into the pulmonary veins. Each lung is completely invested with a serous membrane, the pleura, the visceral layer of this membrane being adherent to the surface of the lung, the parietal layer being reflected from what is called the root of the lung, where the bronchus and the blood vessels enter into the walls of the chest, the outer surface of the pericardium, and the upper hurface of the diaphragm. Beneath this coat there is a rich plexus of lymphatics which communicates with the deeper plexus in the connective tissue, binding together the small lobules.

From these lymphatics there arise vessels which run along with the bronchi and convey the lung lymph to the bronical glands. Nerve branches from the pneumogastric and the sympathetic are found scattered over the lungs, collected together in numerous ganglia, the minute branches being distributed to the muscle tissues of the minute blood vessels and to the walls of epithelium found on the surface.

SECTION III.—Mechanism of Respiration.

The movements in respiration consist of certain rhythmic changes, these rhythmic changes taking place in the thorax partly caused by contraction and relaxation of the murcles and partly dependent upon the elastic character oj the organs. The thorax is a closed box containing two elastic bags which communicate with the external atmosphere by means of the common tube, the trachea. The lungs then form two large sacs divided up into portions or sections, each of which constitutes a small air vessel. These small vessels vary in size, the average diameter being about 1-100 part of an inch. Each air cell has has communication with the small bronchioles, these uniting in their common communication with the trachea. It is estimated that in normal human beings there are between seven and eight hundred million of these minute vessels, representing a superficial area open to the air in the lungs of 200 square meters. In addition to this vast surface, the wall of each air vessel represents a septum dividing the air from the blood in the capillaries, representing a vast vascular surface estimated at about 150 square meters. As the thorax is a vacuum, the pressure of the air inside the lungs stretches and expands these elastic structures so that they are always pressed against the thoracic walls. An increase in the volume of the thoracic cavity is followed by an expansion and a decrease in the volume of the thoracic cavity is followed by a contraction of the lungs. The visceral and parietal layers of the pleura are thus kept in contact with one another. The fact that the lungs are always stretched is shown by what takes place when air is admitted into the cavity of the thorax (the pleura). Under such circumstances the atmospheric pressure exerts its influence upon the external surfaces (the pleural) and upon the internal surfaces of the lungs (the bronichal tubes and air cells.) This elastic bag then collapses, leaving the pleural sac full of air and indicating a condition which patho-

logically is known as pneumothorax. By the activity of the respiratory muscles, the chest capacity is extended on all sides.

This results in a greater atmospheric pressure than that upon the external surface of the lungs, and thus there is forced into the air passages of the lungs, a certain quantity of air which physiologically is called the new or tidal air until the pressure becomes equilibrated, the air remaining in the lungs normally being called the stationary air.

Inspiration is primarily a muscular action. In expiration the relaxation of the muscles, the lungs and the thoracic wall, on account of their elasticity assisted by muscular contraction, causes the chest to recoil into its former position. Thus the internal pressure of the lungs becomes greater than the external pressure and the air is forced out through the trachea. Expiration, therefore, is not purely a muscular action but a result of the elastic structure of the organs. Inspiration and expiration act together and these two stages constitute respiration. If the thoracic cavity is punctured after death, the lungs at once collapse, leaving a large vacuum between the lungs and the thoracic walls. This is due to the loss of elasticity which is found in the lungs when in normal life. During life the lungs are never completely exhausted of air, the air always lodging in the air cells. By inflation of the lungs they always tend to shrink so that they exert an influence upon the chest walls, depending upon the amount of distension, giving rise to the negative pressure which always exists in the thoracic cavity, that is, the pressure always below the atmospheric pressure which considerably influences as we have seen, the blood flow toward the heart. If the thoracic cavity is punctured upon one side only, then the one lung gives up its activity, resulting in the difficulty of breathing. If the other side is also punctured both lungs give up and hence we have asphyxia, because there is no lung expansion, the internal and the external pressure being equalized. The normal condition of the lungs, therefore, is that of partial distension.

In line with this idea, respiration never reaches its maximum of expansion. Complemental air may be forced into the lungs by means of a labored inspiration, due to the expansion of the thoracic cavity under strong muscular activity. Likewise, respiration never reaches its minimum of contraction, for the supplemental air can be forced out by muscular contraction.

Even in this latter case where considerable volume of air is expelled, there is always left what is called residual air. Partial dilation, therefore, is the normal condition of the lungs. There is constantly an elastic conflict between the pulmonary and parietal pleuræ, but this in normal conditions never results in the destruction of either of these because the air cannot penetrate the pleural cavity. In the case of the puncture of the chest wall the air penetrates the pleural cavity, the result being the separation of the pulmonary and the parietal pleuræ, thus forcing out the air through the trachea.

Even in such conditions there still remains a residual portion of air inside the lungs, the infundibula whose walls are soft retaining the air passed from the minute bronchioles. If, however, the air still freely comes into contact with the lungs, the air becomes absorbed, then the lung very soon loses the distended character and becomes hard. In the case of pleural puncture the air is driven out of the cavity, not through the lung at all but, of course, through the opening if the air does not enter the pleural chamber or if some obstruction blocks the puncture then the lungs may be normally distended until the puncture is healed without any g. :at interference with respiration. In the fœtal life there is no air in the lungs, the lungs being in a condition that we speak of as atelectasis, airless. The air cells in this condition have not yet expanded. Those air cell walls are lined with nucleated cells and well rounded cell substance, those cells being adhesive, no cavity having formed during fœtal life. The small bronchial walls also adhere to one another while the larger bronchial tubes and the trachea have a distinct tubular cavity, this cavity being filled, not with air, but with fluid, that is, in the fœtal life. The lungs in the child are in close proximity to the chest walls being separated only by the pleural membranes. At the birth of the child the first volume of air is admitted to the trachea and the larger bronchi passing with considerable force into the bronchioles and the air cells of the lungs, thus separating the walls and filling up the distended cavities. A large quantity of the first inspired air in the new born child remains within the air cells and the air passages and it is only later when they become fully distended that the expiratory process begins, the complete respiration being then established. Although the lungs are very elastic they cannot expell all the air out of the lungs because the air pressure on the internal surface is greater than the elasticity of the lungs and the elasticity of the chest walls. This pressure can be measured, and has been measured by a number of Physiologists. In the dead subject, for example, the manometer can be connected with the trachea. When the collapse takes place in the lungs, then the mercury in the manometer will be found to rise. Donders, a Physiologist, who has devoted considerable time to this subject, found the pressure under these circumstances to be from two to three mm. of mercury. During life this pressure is much greater and it is estimated that during life it is about 7½ mm. of mercury, 6 mm. at the close of a quiet expiration and 9 mm. at the close of a quiet inspiration; that is, this pressure represents about 1-100 part of the atmospheric pressure. In the case of complete forcible distension of the chest the pressure was found to be much greater, estimated to be about 1-25 of the pressure of the atmosphere or about 30 mm. of mercury.

Thus, the pressure upon the heart, and large arteries and veins, and the other organs inside the thoracic cavity would be 754 mm. at the close of a quiet expiration, and 751 mm. at the close of a quiet inspiration. In the living subject the expelling force is greater, because the muscular fibers of the bronchi aid the elasticity of the lungs. This, however, is small compared with the pressure of the lung elasticity itself. By introducing the manometer into the trachea of the animal, through a lateral opening there has been found normally a negative pressure during inspiration. This negative pressure being indicated by the fall of mercury in the manometer and, on the other hand, a positive pressure during expiration indicated by the rise of the mercury in the manometer. The same negative and positive pressure may be found by introducing the manometer into the trachea through the mouth, or the nostril, the amount of pressure being determined by the strength of the inspiration, and by the strength of the expiration. The negative pressure, therefore, increases according to the depth of the inspiration, that is, according to the extent of the lung expansion. During expiration it returns to the normal at the beginning of the stage of inspiration. The internal pressure of the chest cavity is called the intra-thoracic pressure, and it differs from the pressure inside the lungs, this pressure being called the respiratory pressure. The thoracic cavity may be enlarged on all sides. Ideally it forms a cone, the apex of the cone being placed at the neck, and the base of the cone resting upon the diaphragm, the sides of the cone being represented by the intercostal and the other muscles of

respiration together with the ribs, the sternum and the vertebrate column. On account of this an enlargement of the thoracic cavity lessens the pressure upon the lungs while a diminution of the thoracic cavity increases the pressure upon the lungs, these conditions favoring the inflow and outflow of air through the trachea, which is the only opening between the air and the lungs. This is the condition normally found in inspiration and in expiration. When the thoracic cavity enlarges the elasticity of the lungs yields, following as it were, the traction action of the chest, the two being in close apposition, and only separated from one another by the two pleural layers.

The spirometer has been made use of by some Physiologists, to measure the greatest amount of air that can be forced out of the lungs by the strongest, expiration, accompanying of course the deepest possible inspiration. The amount, as estimated by the Physiologists, varies from 2000 to 4000 cubic centimetres, of this amount about 500 cubic centimentres represent tidal air, or the new air taken in at each inspiration. From 750 to 1000 representing the supplemental air, 750 to 1000 representing complemental air and about 1400 cubic centrimetres, the residual air. All of these combined together constitute what is called the vital capacity of the lungs, that is, the sum of the tidal complemental, the supplemental and the residual.

Inspiration.—In inspiration the cavity of the thorax is enlared in two ways. 1st of all, it is enlarged vertically. The vertical diameter is increased by the contraction and the descent of the diaphragm, the anterior abdominal walls in this case protruding. In the human subject, the diaphragm is a partition wall separating the thorax from the abdomen, elliptical in shape, the convex part being direct toward the thorax. On the contraction of the muscular fibers, the middle part of the diaphragm descends and the diaphragm becomes flattened. From the sides the diaphragm descends further than from the central part. The cardiac portion of the diaphragm is said to descend from 5 to 11 mm. during normal inspiration. The arch is thus diminished in its height and on account of the attachment the first three lumbar vertebræ, to the lower six costal cartillages and the adjacent parts of the ribs there is always a tendency to pull in and also to pull up these lower ribs and also the costal cartlages, together with the lower end of the sternum. This is compensated for by the abdominal pressure. After the contraction of the diaphragm there is a negative pressure in the thoracic cavity, this pressure driving the diaphragm upward to the normal position in which the lower part of the diaphragm is in close proximity to the chest walls. This pressure downward is transmitted to the abdomen, especially to the anterior abdominal wall, producing a bulging outward and thus enlarging the thoracic cavity vertically during the process of inspiration. 2nd. The cavity of the thorax is also enlarged antero-posteriorly and transversely by the elevation and rotation on the antero-posterior axis of the ribs and by the carrying forward of the sternum. These movements are the result of muscular contractions. As the thorax enlarges the lungs also, necessarily enlarge otherwise there would be left a vacuum between the pulmonary and the parietal layers of the pleuræ. This increased expansion of the lungs, means the rarefaction of the gases that are contained within the lungs, that is, the pressure of the gas inside the lungs falls below the pressure of the gas of the external atmosphere. The external atmosphere rushes down the trachea until the equilibrium is restored between the internal and the external. These two main causes of the enlargement, the descent of the diaphragm and the elevation of the ribs give us respectively the two kinds of breathing, said to be characteristic diaphragmatic breathing, characteristic of the male and costal breathing characteristic of the female. Physiologists have found out that both of these characteristic forms of breathing are really present in every respiration, the one, however, prevailing over the other in the one case. These differences it is said by some Physiologists depend upon the difference in sexes. This, however, is untrue. The difference in breathing does not really depend upon difference in sex, but as has been said upon heredity upon difference in the female costume as compared with the male costume. That this point is true is evident, for in the case of children of both sexes there is no difference in the form of breathing. The diaphragmatic characteristic male breathing being found in all children. The lowering of the diaphragm is mainly due to the muscular contraction. The elevation of the ribs and their rotation howeverare more complicated.

In the diaphragmatic breathing the vertical diameter is increased with a slight increase in the antero-posterior diameter. In the costal breathing, on the other hand, the antero-posterior and the transverse diameters are increased by the movements of the upper ribs raised by the scaleni muscles, producing what is characteristic of that form of breathing, the heaving of the chest, the diaphragmatic breathing, in this case, being reduced to a minimum. In the case of abdominal tumors, the breathing is thrown up into the clavicular region of the chest. In the adult life the antero posterior diameter is estimated at 165 mm. in the upper portion, and 190 mm. at the base; the transverse diameter at the axillae in the male is 260 mm. and in female 240 mm. In the case of the antero posterior and transverse enlargements of the chest the enlargements take place, as we said before, largely by the movement of the ribs. These ribs may be considered as radii moving on the vertebral arthrosis as a center. At rest the rib is obliquely directed from the spine toward the sternum. When it moves freely its sternal attachment moves forward more horizontally further away from the spinal center. As all the ribs have a slanting direction downward, on being raised they push the sternum forward; this forward movement being more or less according to the length of the ribs. The frontal surface of the chest is thus pushed forward and also upward according as the ribs are elevated. The rib arch, therefore, increases from the first to the seventh ribs, the elevation of the lower ribs thus increasing the antero posterior diameter and also the transverc diameter, thus making provision for a very considerable enlargement of the chest. This elevation of the ribs takes place by means of muscles. The muscles that are concerned in ordinary inspiration are the diaphragm, the external intercostals, some Physiologists also say the internal intercostals, the levatores costarum, the serrati postici muscles, both the inferior and the superior and also to some extent, the scaleni muscles. Aside from the diaphragm the external intercostals are the most important in connection with inspiration. The act of elevation over the entire chest is greatly assisted by the fact that the second rib is more movable than the first rib, thus furnishing a more solid base upon which the muscular action rests. Each rib in turn from the first onwards supporting the next rib the scaleni acting as an additional base of support for the first two ribs, forming a solid foundation for the action of the external intercostals. In this way there is formed a very solid base for the action of the external intercostal muscles.

In deep inspiration the sterno-mastoid raises and supports the first two ribs, by pulling up the sternum and fixing the clavicle so as to form a solid foundation for the musculsr action of the chest. The serratus-posticus

superior also raises the upper ribs, fixing the 2d rib, and raising the 3d, 4th, and 5th ribs, the serratus-posticus inferior aiding the diaphragm by drawing the lower four ribs backward, and in deep inspiration downward; the quadratus lumborum and the other muscles, by depressing and fixing the lower ribs form a solid basis for the contraction of the diaphragm, and thus, materially assist in deep inspiration. The intercostals, according to some Physiologists, aid in inspiration; according to others, the parts of the intercostals between the sternal cartilages act as inspiratory muscles, while those parts between the ribs act as expiratory muscles. According to other Physiologists the intercostals take no part in inspiration, simply acting as strengthening muscles, to render the intercostal spaces, and the whole of the chest cavity, firm and solid, giving tension, therefore, to the intercostal spaces.

In forced inspiration certain other muscles are brought into play, for example, the scaleni muscles, give a firm support to the first two ribs. The serratus-posticus superior gives fixity to the 3d, 4th, and 5th ribs, and by their contraction, the contraction of the scaleni and serrati being vigorous, they raise those ribs. The false ribs become lowered and then fixed, adding support to the diaphragm so that it vertically enlarges the chest. In artificial respiration and in forced respiration, with the fixation of the upper limbs, the pectoralis minor, the serratus magnus and the ilio-costalis aid in inspiration, elevating the ribs, and thus increasing the size very materially of the thoracic cavity. In fact all the muscles of the body which can either raise the ribs or aid in fixing the other muscles, are brought into play in forced inspiration.

Expiration.—In normal expiration the walls of the chest and of the lungs, as we said before, recoil. In inspiration the lung tissue is stretched, this tension continuing as long as the muscle contraction lasts. As soon as the inspiratory muscles relax, the elasticity of the lungs comes into action and drives out a quantity of the air. This expulsion being due, not to muscular action but to the elastic recoil of the muscles. By the ascent of the diaphragm and the springing back of the ribs to their normal position, the cavity of the thorax is decreased. The lungs, therefore, during expiration occupy a much smaller space than before during inspiration. This means then, that their contained gases must occupy a smaller space than they did during inspiration.

Hence the pressure inside the lungs becomes greater than the pressure of the external atmosphere. The gas under this pressure rushes out of the lungs through the trachea in order that a state of equilibrium may be regained. Inspiration, as we said before, is the result of muscular action; whereas, expiration is a passive process, at least in the case of ordinary expiration, being in the main the result of elastic recoil, this elastic recoil being due to the lung tension and also to the tension of the costal cartilages, the intercostal spaces and the abdominal walls. The elastic lungs and the ribs as soon as the muscles of inspiration relax or let go their hold upon the chest spring back to their original form and size. Ordinary expiration is not, then, the result of muscular contraction. Some Physiologists hold that the intercostal muscles, especially the internal, act as expiratory muscles by depressing the ribs. After normal expiration the lungs are in a condition of elastic tension. When the muscles of inspiration cease to act, this tension comes into operation. The borders of the costal cartilages which are twisted upward and outward during inspiration, become during expiration untwisted. The intercostal spaces which were stretched during inspiration react and loose the distension during expiration. The diaphragm also relaxes pressing back the abdominal walls into their place and pushing up the diaphragm into its normal resting position. In addition to these influences there is another influence, the weight of the chest wall, this weight of the chest wall tending to return the chest to its normal position. It is generally supposed by Physiologists that the internal intercostal muscles contract during expiration, acting the part, therefore, of depressors of the ribs. This activity, however, is probably to maintain the tension of the intercostal tissues, not to depress the ribs. When this expiration becomes forced certain of the muscles become active. The internal intercostals, for example, during forced expiration are very active, at least when the lower portion of the thoracic cavity becomes fixed, this fixation taking place through the action of the abdominal muscles. The fixation is accomplished by the contraction of these abdominal muscles pressing the abdominal viscera against the diaphragm, causing the diaphragm to be pushed upwards, diminishing the vertical measurement of the thorax. The triangulares sternit lying behind the costal cartilages reach upward and then outward from the lowerend of the sternum, the deep surface of the ensiform cartilage and the cartilages of two or three of the lower sternal ribs to the lower and the deeper surfaces of the cartilages of the 2d, 3d, 4th, 5th and 6th ribbs. In this way we have the depression of the cartilages during expiration.

The serratus posticus inferior arising from the spines of the last two dorsal and the upper two lumbar vertebræ, passes outward, upward and forward, being inserted into the lower borders of the last four ribs. During expiration they pull the ribs downward and then backward. The levatores ani come together from the pelvic wall forming the greater part of the muscular floor of the pelvic cavity and acting as a resistant to the downward pressure of the viscera produced by the strong contraction of the abdominal muscles. The abdominal muscles assist in lessening the thoracic cavity by presenting a solid foundation upon which the internal inter-costal muscles act by pulling in the lower part of the sternum and the lower ribs, and by causing the diaphragm to move upwards by the force of the abdominal viscera. As expiration becomes more forced all the muscles which can aid in depressing the ribs or which can assist in giving fixation to the muscles, are brought into play so that the entire body according to its muscles and cartilages, is brought into action in forced expiration.

Associated with these movements of the thoracic walls, which take place in respiration, certain other muscular movements also take place. The currents of air that pass in and pass out of the lungs travel through the nasal cavity, more especially along the inferior nasal meatus. With each inspiration there is slight expansion of the nostrils, due to the contraction of the dilatores naris and in this way the entrance of air is assisted. By passing through the nasal membrane warmth is imparted to the air and the mouth is also protected from the dryness of the air. During expiration on the other hand, the nasal cartilages spring back to their original size, their normal form and position, aided by the compressores naris. The soft palate is moved backward and forward by the current of air ingoing and outgoing during inspiration. The glottis is wide open, while during expiration the arytenoid cartilages approach each other and the cartilages of Santorini project inward. Thus simultaneously with the movements of the alæ nasi and the thoracic walls there is a widening and a narrowing of the glottis. When this breathing becomes labored, the mouth is generally thrown open, the soft palate arises under the influence of the levatores palati, the larynx descending by the action of the sterno-hyoid and the sterno-thyroid muscles

and the glottis is thrown wide open as the result of the action of the posterior crico-arytenoid muscles, the naris being distended by the action of the posterior and the anterior dilatores nars and the alæ are raised by the levatores labii superiores alæque nasi the muscles supplied by the facial nerve being brought into action in opening the mouth.

The muscles of respiration are as follows :

First of all, the diaphragm. The diaphragm is the principal inspiratory muscle. On the contraction of the diaphragm the central part descends and it becomes less convex above, increasing the diameter of the thorax and the depth of the posterior part of the cavity. The phrenic nerves together with the sympathetic fibers furnish the nervous connection.

2. The levatores costarum arise from the points of the transverse processes of the highest dorsal vertebrae and the seventh cervical, passing downward and outward they find insertion in the external surface of the rib associated with the vertebrae. These muscles are rib elevators and are supplied by the intercostal nerves.

3. The intercostales externi. These pass between the ribs passing downward and forward, extending from the rib tubercles to the external cartilages. These muscles are also rib elevators and are provided with nerve connections in the intercostal nerves. The intercostales interni between the cartilages also assist in the elevation of the ribs.

4. The sterno-cleido-mastoids pass from the mastoid process to the sternum and the clavicle, assisting in the elevation of the upper portion of the chest in deep inspiration. These muscles are connected with the spinal accessory nerve and one of the branches of the second cervical.

5. The scaleni muscles assist in pulling up the first and second ribs under the fixation of the neck, being supplied with nerve connection by the cervical nerves.

6. The serrati postici superiores elevate the ribs in the upper part of the chest in forced inspiration, being supplied with nervous connection by the intercostal nerves.

7. The pectorales majores and minores, when the shoulders are fixed, assist in elevating the ribs, being supplied with nervous connection by the anterior thoracic nerves.

8. The trapezei muscles assist in fixing the shoulders, being furnished with nerves from the 3d and 4th cervical, and from the spinal accessory. The rhomboidei muscles also assist in the fixation of the shoulders, forming the base for the action of the pectorales muscles, receiving their nerve branches from the 5th cervical.

9. The erectores spinæ are complex muscles reaching along the sides of the spinal column, straightening the spine and assisting in the elevation of the sternum. They receive their nervous connection from the spinal nerves.

10. The intercostales interni run downward and backward from rib to rib, acting as depressors of the ribs in expiration. These muscles being chiefly used to preserve the intercostal pressure. The intercostal nerves supply these muscles.

11. The serrati-postici inferiores arising from the spine, running outward and upward, to be inserted into the lower edges of the last four ribs, drawing the ribs downward and forward, and increasing the lower part of the chest cavity. These muscles are supplied with nervous connection from the intercostal nerves.

12. The abdominales muscles press upon the abdomen, pushing upward

the thoracic base and aiding in the expulsion of air from the lungs. These muscles also assist in pulling down the ribs and contracting the diaphragm, thus aiding in expiration. They are supplied with nervous connection by the lower intercostal nerves.

13. The triangulares sterni draw downward the attached costal cartilages in expiration, these muscles being supplied with nervous connection by means of the intercostal nerves.

SECTION IV.—Respiratory Movements.

From what has been said it will be evident that each respiration consists of, 1st, the period of inspiration. 2d. The period of expiration, and 3d. The short period of pause during which there is no movement. In normal breathing the respiratory movements follow each other in regular succesion, the expiration being longer than the inspiration. In certain circumstances, as for example, in the case of the excitation of the vagi inspiration becomes two or three times longer than expiration. This, however, is an abnormal condition due to irritation. The pause may be either long or short, the length of it depending largely upon two things, 1st of all, habit, and 2d, will. In quiet breathing the pause occupies about one fourth of the whole period of respiration, the pause being shortened if respiration is very active and being increased during sleep, unconsciousness and mental abstraction. The respiratory rate also depends upon difference in age, position, species, temperature, that is, internal temperature, the seasons of the year the activity of the body and the digestive process.

In the normal adult the respirations number about 15 to 17 per minute, that is, about one respiration to four or five cardiac pulsations. These respiratory movements are more frequent in the child and are influenced largely by the movements of the body, exercise, etc. In old people the average rate of respiration may be found reduced to ten or eleven per minute. It is said by some Physiologists that the size of the body affects the rate of respiration, the smaller the body the more frequent being the respiration. In the male, and in children inspiration depends chiefly on the descent of the diaphragm and the breathing is abdominal. In the mature female the chest capacity is increased transversely and antero-posteriorly, the breathing being principally thoracic or costal.

When the inspirations are very deep, the distinction between the costal and the diaphragmatic breathing disappears altogether. During sleep, the difference of breathing in the sexes also disappears; the respiration during sleep being entirely thoracic. By the use of the stethoscope in connection with the larynx and the trachea, two sounds are heard, the one inspiratory and the other expiratory. These are called the laryngeal and the tracheal sounds which are harsh, articulate, the inspiration and the expiration being of equal length with a distinct interval between them. To the right or to the left of the manubrium of the sternum, similar sounds are heard. These sounds, however, are less intense and are called bronchial sounds. Over the posterior tube of either lung, heard either from the back or from the chest, we find respiratory murmurs, two low rustling sounds, the expiratory sound being ⅓ of the length of the inspiratory sound, with no interval between the two These sounds are produced by the air passing through the trachea the bronchial tubes and the lungs. In abnormal conditions the murmurs assume different forms, called rales or souffles. Listening to these sounds during speech produces certain special forms, which are called pectoriloquy when the voice sounds through the trachea, bronchophony when

sounded through the bronchial tubes, no audible vocal sound being heard in connection with the lungs. By fluid effusion into the pleural cavity a peculiar vocal sound is heard over the middle and posterior part of the thorax. This sound is of a short tremulous and a sharp character, also peculiarly metalic in its character, called ægophony.

The amount of air passing into and issuing from the lungs may be measured by means of instruments, these instruments being called the spirometers. The Hutchinson spirometer is the best of them. This instrument is made on the principle of the gasometer for the purpose of storing gas. Casella has invented an instrument on the principle of the anemometer used for recording the velocity of wind by Meteorologists. Bergeon and Hastus have also invented an instrument which they call anapnograph. A valvular plate forms one side of a rectangular box. It is connected by means of a tube with the mouth attached to the axis of this plate, there is a light lever with the point which writes upon the blackened paper surface moved by clockwork. The air passes through the tube into the box and comes into contact with this valvular plate, the pressure changes being transmitted to the valve and being recorded on blackened paper surface. By the graduation of this instrument to suit small squares of blackened paper tracings can be taken which represent not only the air pressure but also the amount of air that is inspired and expired and the velocity of the air current. The elastic lungs, even after a forced expiration, still contain a quantity of air, this quantity of air being generally estimated about 100 cubic inches. This volume of air is called the residual air. At the end of an ordinary expiration the emptying of the lungs is not nearly so complete, an additional 100 cubic inches still remaining in the lungs. This second 100 cubic inches is called the supplemental air, so that after a normal expiration 200 cubic inches of air remain in the lungs. The amount of air that is taken in at each ordinary inspiration measures about 30 cubic inches, this is called the tidal air. By a deep inspiration the lungs may be made to contain an additional volume of air roughly represented by another 100 cubic inches, this last 100 cubic inches being called the complemental air. Hence the maximum capacity of the lungs may be estimated at 330 cubic inches, Of this volume of air—330 cubic inches—only 230 cubic inches can be expelled by the most forcible expiration, following a very deep inspiration. The term, vital capacity is applied to this maximum amount of air that can be contained within the lungs. As a rule the vital capacity is greater in the male than in the female, increasing up to 35 years of age and after that period of life diminishing. It, also, increases normally with the height and the internal capaeity of the chest. Each centimeter added to the height of the body representing about 52 cubic centimeters in the male and 30 cubic centimeters in the female. In the normal male adult of about 5ft in height the vital capacity would be about 2,350 cubic centimeters and in a female of the same height, about 2,000 cubic centimeters.

Various instruments have been invented for the purpose of recording the inspiratory and the expiratory movements. Marey's stethograph is, perhaps, the one that is most commonly used. The movements of inspiration and expiration are, 1st of all, communicated by a system of levers to a tambour passed through a rubber tube to a second tambour, which has a lever to record the tracing on the kymograph. In the case of the costal movements, the stethograph is always used. In the case of diaphragmatic movements, a long instrument is passed through the walls of the abdomen, between the liver and the diaphragm, so that the one end which is flat or spoon shaped, rests between the abdomen and the liver, the other end which is pointed, rests upon the recording lever, while the walls of the abdomen act as a fulcrum to the lever. In this way the movements of the diaphragm may be followed and traced out just as we found the tracing in connection with the arterial pulse and the heart pulsations. It has been found by studying these tracings 1st, that expiration succeeds inspiration without any pause. 2nd, that expiration is longer than inspiration, except in abnormal conditions. 3d. The inspiratory movements are sudden and abrupt as compared with the expiratory movements. 4th. There is an expiratory pause at the close of the expiration, this expiratory pause being normally very brief. These represent the four main points that now are settled in Physiology by the use of these instruments. In certain diseased conditions there is an inspiratory pause following the inspiration. When the respirations become abnormally irregular, then the pause is increased, this applies to the inspiratory pause, and also the expiratory pause. Some Physiologists have tried to measure the force of the inspiratory muscles. These muscles require to overcome both the thoracic and the pulmonary elasticity. These resistances may be measured by a tube with what is called the "T" junction connected with the short limb of the manometer, placed in the two nostrils, and then making an inspiration. The mercury rises in the short limb representing the negative pressure, estimated as ranging from 1 to 3 mm. of mercury in the normal case, and from 30 to 60 mm. in the case of forced inspiration. In quiet expiration a positive pressure is noticed, varying from 2 to 3 mm. in the normal, and from about 80 to 120 mm. in forced expiration. By making an average we find that the inspiratory muscles need to overcome a resistance, amounting to 10 mm. in the normal, and about 80 mm. in forced inspiration. During forced expiration there must be a force sufficiently strong to overcome a resistance equal to the positive respiratory pressure of the lung minus the lung elasticity, or about 70 to 75 mm. of mercury. The lung elasticity may be measured also in normal respiration by the use of the manometer, the estimates representing it being about 6 to 8 mm. of mercury in normal respiration, and about 30 mm. of mercury in deep inspiration.

The lung contractility has also been measured by various Physiologists, although the contractility of the lung is smaller because the contractility arises from the muscle fibers of the bronchi and therefore, generally plays a very unimportant part in either inspiration or expiration. According to the various methods that are used in registering the movements of inspiration and expiration, tracings may be obtained slightly varying from one another, all of them being more or less imperfect on account of the difficulty of inventing an ideal method. Inspiration commences suddenly, advances rapidly, becoming gradually more rapid, being followed immediately by expiration, which begins rapidly and then gradually becomes slower. In normal breathing hardly any pause exists, although there is a slight pause whenever the respiration becomes unrhythmical. Marey's pneumograph which is largely used in connection with these measurements consists of a hollow elastic cylinder, the internal cavity being connected with a tambour. The cylinder can be strapped around the chest and so adjusted as to indicate all the movements. On the expansion of the chest the cylinder ends are drawn out and the air in the cavity becomes rarefied, the lever which is attached to this cylinder being lowered, the lever being raised when the opposite process takes place. In the case of the stethometer which consists of a rectangular framework made of two solid parallel bars joined to a cross bar. The free ends of the bars are arranged, the one

with a tambour and the other with a button attachment. The tambour carries on the metal plate of its membrane, a small button. When the chest diameter is to be measured by this stethometer, the instrument is placed around about the chest, the button at the one end being placed on the spine and the tambour on the sternum, the changes in the diameter causing variations of the pressure in the tambour receiver, these changes or variations of pressure being transmitted to the tambour recorder and recorded by the recording lever, on the traveling surfaee. Inspiration and expiration vary, as we said before, with age and also with the sex of the individual, the inspiration being briefer in the case of the female and in children and old people. Variations in inspiration and expiration are also found in certain abnormal diseased conditions. If the pneumogastric is divided or in pathological conditions involving the stricture of the air passages the expiration becomes shorter than the inspiration. In the case of the dilatation of the air vessels the expiration is longer. In the new born child the ratio of inspiration and expiration is about 1 to 2 or 1 to 3. In the adult this ratio becomes about 5 to 6 normally. Inspiration is more abrupt and sudden than expiration, the tracings that we have mentioned indicating the rapid movements of inspiration as compared with the slower movements of expiration.

The normal pause varies abnormally in abnormal conditions, representing either an inspiratory pause or an expiratory pause. During sleep the normal rhythm of the periods, both of inspiration and expiration is broken, particularly in the case of children and aged people. In the latter case this pause becomes sometimes characteristically expiratory. This disturbance of the respiratory rhythm, is characteristic of what is called the Cheyne-Stokes breathing, in which we find respiratory movements in a series, each series being separated from the next preceding and next succeeding series by a marked pause. The first respirations of each series are superficial, then the respirations gradually become deeper until they reach a maximum, after that they gradually become more superficial until the close of the series. This series normally consists of from 20 to 30 respirations. This kind of breathing we find in connection with cerebral pathological conditions, for example, uraemia or the toxic condition of the blood arising from the accumulation of urea, and it indicates always the near approach of death. The same or similar disturbances of the periodicity of respiratory movements are found in the last stages of asphyxia and in cases of poisoning by chloral or curare, and in certain stages of fevers caused by the absorption of septic substances. There is a marked variation in respiratory periods in the case of age, in the newborn child the average being about 45 per minute, in a youth of 15, about 20; at 30 years, about 18; at 35, from 17 to 15; and in old age, from 11 to 10. The position of the body influences the periods also, the lying posture representing a slower respiratory rate, the sitting posture a more rapid rate, and the standing or walking attitude the most rapid rate. During the night the respiratory rate is much less rapid than during the day, and during or after meals it is much more rapid. Muscular activity also increases the rapidity of respiration. The changes of temperature outside the body have almost no effect, while temperature changes in the body affect very considerably the rate, as it rises in the case of fevers very much like the pulse rate, the pulse rate and the respiratory rate in abnormal as well as in normal conditions being in a regular and almost invariable ratio of 1:4 or 1:4½. Psychic influences also affect the respiratory rate, mental excitement or volitional purpose exerting a strong influence on its rapidity,

SECTION V.—The Influence of Respiration on the Circulation.

The movements of respiration are accompanied by very characteristic changes in the circulation. If the blood pressure is represented in a tracing and also the pulse tracing, these movements can be noticed if side by side we place a tracing of the inspiration and expiration. If the brain of a living mammal is exposed by removing the skull there is noticed a rhythmic pulsation of the cerebral mass quite different from the pulsation of the brain arteries. These pulsations of the cerebralmass are simultaneous with the respiratory movements, the cerebral mass rising during expiration and sinking or yielding during inspiration. If the arteries of the brain are ligatured these pulsations will cease altogether, or if the venous blood is allowed to escape from the venous sinuses they will also cease. These pulsations arise, therefore, from the expirations and the inspirations that restrain or assist the blood flow from the brain. During inspiration the pressure of the blood in the large veins may be negative, that is, it may fall below the atmosphere, and the puncture of one of these large blood vessels may result fatally on account of the inspiration of air into the vessels, passing through the vessel into the heart. A venous pulse may be observed in these large vessels of the neck, the pulsation always accompanying expiration and inspiration. The expansion and the contraction of the thorax have a strong influence upon the blood flow through the thoracic cavity, indirectly influencing the whole vascular system. The blood pressure rises shortly after the beginning of inspiration, usually after a period equal to about two or three heart pulsations, and it attains its maximum after a short period following expiration. Afterwards the blood pressure begins to fall, reaching its minimum after the commencement of the succeeding inspiration. The pulse rate during inspiration is more rapid than during expiration, and the curve represented in the tracing is different. Blood pressure changes, therefore, result from the respiratory movements, the effects upon the blood pressure varying according to the character of the respiration. The lungs and the heart, as we said before, are suspended in an air-tight cavity, the thorax and lungs being distended through inspiratory action, the walls of the air-cells in the lungs having an elastic force depending upon the amount of the lung distension. This elastic force which tends to lead to the lung collapse, exercises a suction force upon the other organs inside the thoracic cavity. This negative pressure becomes stronger as the lungs are more fully distended. This negative pressure inside the thoracic cavity is called intrathoracic negative pressure. This intrathoracic negative pressure in the case of sheep, rabbits and dogs is said to amount to from 3 to 5 mm. of mercury.

The pressure on the chest organs must have been atmospheric pressure, minus the negative pressure, and also, minus the elastic force of the lungs—that is, 760 mm., minus 3, minus 9, or about 748 mm. In normal expiration there is a force pressing upon the chest, equal to the atmospheric pressure together with the positive pressure of expiration, minus the intra-thoracic negative pressure, that is, 760 mm. plus 2 mm., minus 6 mm., amounting in all to 756 mm. During respiration, therefore, the pressure upon all the thoracic organs, except the lungs, is always less than that upon the vessels outside the chest, that is, the pressure upon the organs in the thoracic cavity other than the lungs, is always less than the atmosphere, the negative intrathoracic pressure being greater during inspiration. Thus, the aspiratory action of respiration attracts the blood from outside the thoracic cavity

into the large vessels that lie inside the thoracic cavity, both during inspiration and expiration, more largely however during inspiration. The thoracic organs being suspended in an air-tight cavity, when the lungs are distended during inspiration, and the intra-thoracic pressure is increased, the heart which is a hollow elastic muscle, is also affected by this pressure. The effects however, are very different, being more favorable to the venous blood flow, and retarding the arterial blood flow. The chief influence, however, is upon the flaccid and yielding veins that lie close to the heart. If the chest cavity is opened the inspiratory action ceases to expand the lungs, and there is no distension of the heart or the large blood vessels.

If, however, in the living subject the trachea is compressed, the inspiratory action becomes greatest upon the heart, the highest influence upon the circulation being noticeable in these circumstances, hence, it is said the maximum influences of the respiratory movement is always upon the heart or on the vessels close to the heart. This influence, as we have said, is felt more upon the large vessels than upon the heart itself, on account of the fact that the heart is a strong muscular substance, whereas, the vessels are soft and yielding. In the large vessels themselves this influence is felt more upon the veins than upon the arteries, on account of the softer walls of the veins and the thicker, more unyielding walls of the arteries. During inspiration the pressure upon the aortic surface is less, the aorta being distended and the blood flow through the aorta being lessened, producing a fall in the blood pressure. The thick aortic walls will give way less to the distension than the thinner vein walls, so that inspiration does not materially affect the aorta and this effect is always counterbalanced by the distension of the large veins, and by the rapid blood flow out of the veins into the heart. This flow of blood from the lungs throws more blood into the heart, which passes through the heart and is thrown into the aorta. Thus the greatest respiratory influence is felt, in the relaxed and relaxing walls of the large veins. The lungs, the heart and the large vessels being suspended in the expandible cavity of the thorax in which they rest, the lungs communicate with the atmosphere, and the heart and the vessels with the blood vessels outside the thoracic cavity.

These are all subject to the influence of distension and contraction in connection with the respiratory movements. In the case of the lungs themselves, the blood vessels communicate with the external vessels, inspiration diminishing the pressure on the delicate walls of the pulmonary vessels assisting the dietension of these vessels and promoting the blood flow from the lungs to the left auricle without almost any appreciable effect in the pulmonary arteries. The minute capillaries on the aircell walls are also subject to greater pressure than the pulmonary veins in inspiration, and thus the flow of blood is stimulated. The thoracic aspiration may draw in air, this air being carried to the right side of the heart and to the pulmonary capillaries. If the amount of air that is sucked in is large, it causes an obstruction in these minute capillaries, often resulting in death. During expiration the negative pressure is lessened, the intra-thoracic vessels returning from their dilated condition to a normal condition. The pulmonary blood vessels are thus left free to relax and are also interpressed by the air pressure of the lungs and by the expiratory influences, resulting in the contraction of the pulmonary vessels. More blood is thus brought into the chest and also into the heart during inspiration and the blood flow through the lungs is more free, more blood finding its way to the left side of the heart and hence into the general sytemic circulation. This increased blood supply causes the general blood pressure to rise during inspiration while it is lessened during expiration. In deep inspiration the elastic action of the lungs and the intra thoracic pressure become greatly increased; consequently the pressure upon the organs inside the chest is much lower than the pressure of the atmosphere. Forced expiration, on the other hand, produces a positive pressure, often amounting to 100 mm which added to the atmospheric pressure would represent about 860 mm; the intra thoracic pressure being lessened we must substract it, leaving 854 as representing the pressure on the organs of the chest. In this case the veins are very much enlarged and the blood is prevented from flowing into the heart, the veins presenting a characteristic venous pulsation during forced inspiration and forced expiration.

The blood flow to the right side of the heart is also assisted by the action of the diaphragm and of the abdominal walls, transmitted to the abdominal vesself. Arterial pressure tends to force the blood downward in the body and to restrain the blood flow from the heart, while the flow toward the heart in the venous-system is increased on account of this respiratory movement. The arterial walls are so thick and so rigid that this influence does not materially affect the arterial blood flow, whereas, the venous walls being so thin and yielding, it tends to facilitate the flow of the blood toward the heart. The result of this would be seen in the case of the section of the phrenic nerves, producing diphragmatic paralysis, the blood pressure curves in this case being very much lessened. This is due to the diminished respiratory actions which are confined to the ribs and to the sternum. and also to the loss of the pressure communicated from the diaphragm to the veins.

The general effect, therefore, of inspiration, is to increase the blood pressure and the general effect of expiration is to decrease the blood pressure. The negative pressure in the thoracic cavity found during inspiration gives place to a gradual lessening of the negative pressurc and to a diminution of aspira tion resulting from an intra-thoracic pressure below the atmosphere. The flow of the blood is also lessened because a smaller volume of blood passes through the large veins. The veins in the abdomen are now being refilled with blood and as the lungs contract, the vessels inside the lungs also contract, retarding the blood flow from the right side of the heart through the pulmonary circulation to the left side of the heart.

Hering has devised an instrument to illustrate the influence of the respiratory movements on the circulation. There is a large conical chamber representing the thorax, at the bottom of which there is a rubber representing the diaphragm. At the top of the vessel there is a tube entering into the chamber representing the trachea connected to the manometer from one side. At each side is a vessel, one filled with water representing the venous blood and the other empty, these two communicating by a tube with a long soft bag between the tubing, which represents the heart, the heart valves being at each end of the bag representing the valves in the heart at the orifices. In the cavity there are suspended from the tube representing the trachea, two sacks representing the lungs. If the diaphragm is pulled down from the center the air in the chamber becomes rarefied, the air passing through the trachea tube into the lung sacs; at the same time water is forced from the vessel on the one side with the heart sac which becomes dilated. The diaphragm when released is pulled up partly by the negative pressure in the cavity and partly by the diaphragm elasticity. Then the rubber sacs are emptied by their own elastic reaction. The heart sac contracts, forcing the fluid into the vessel on the other side, the flow being measured on the manometer. During inspiration there is a negative pressure in the thoracic

cavity gradually increasing during the inspiratory period, air being breathed into the lungs and blood being sucked into the large veins next the heart. During expiration this negative pressure gradually diminishes, the air being driven from the lungs and the blood being driven out of the distended veins into the heart. This blood flow into the chest during inspiration is assisted by the distension of the capillaries of the lungs and by the difference in pressure between the veins and arteries so that the blood circulation in the lungs is increased and the blood circulates with greater rapidity.

The aspiration of the thorax also assists in drawing the blood away from the liver, for when inspiration reduces the pressure on the inferior vena cava, the blood flow through the hepatic veins and the rather slow normal circulation in the liver becomes gradually accelerated. Some Physiologists believe that the rhythmical stimulation of the vaso-constrictor center in the medulla is influenced by respiratory actions. These rhythmical stimulations are said to take place simultaneously with the inspiratory action of the respiratory center. In the case of the human subject it is noticed that during inspiration the heart-beat increases, inspiration assisting, at least, in this way in increasing the general blood pressure. During expiration the pulse is less rapid than during inspiration. If the pneumogastric nerves be cut the pulse rate increases, but there ceases to be any difference in it during inspiration and expiration. If, however, the thorax be opened and the pneumogastrics left uncut there is still an increase in the rate during inspiration. Thus, the cardio-inhibitory center either increases in activity during expiration or else loses activity during inspiration, the cardio-inhibitory center and the respiratory center being associated in some way in their action. This sympathy between these two centers is supposed to depend upon the arterialization of the blood, the greater arterialization of inspiration affecting the cardiac centers, lessening its activity during inspiration and producing an increased pulse rate. Deficient arterialization of the blood affects the vaso-motor system. By placing an animal under the influence of curare so as to remove the complications arising from the skeletal muscle contractions, if both vagi are divided so as to check the inhibitory impulses from the center, artificial respiration becomes suspended. Following this there is noticable a rise in the pressure due to the stimulation of the vaso-motor center by the venous blood flow producing constriction of the small arteries, especially those of the splanchnic region. When the artificial respiration ceases the blood pressure rises, at first, steadily and then more irregularly. As the blood becom es more venous the vaso-motor centers and the heart become weakened. The blood pressure waves produced during normal breathing become more marked as the respiratory movements increase in depth. When the most powerful inspiration is made the lungs are fully expanded and the heart is also greatly distended, the intra-pulmonary and the intra-cardiac vessels being also dilated. Although this induces a large flow of blood into the chest cavity, the heart beats may be small, because the negative pressure is so great that the thin walls of the auricles have to contend against a great pressure in contracting. Only a small quantity of blood is thus forced into the general circulation and the left auricle of the heart through the lungs. If there is a very strong expiration, followed by a very powerful inspiration, the mouth and nostrils being closed, the heart and the vessels become greatly distended, the blood current to the auricles and ventricles increases; the heart and lung vessels become gorged, only a very small quantity of blood passes into the systemic circulation, and the heart sounds and pulse may disappear. If then a powerful inspiration is made and then a strong expiration, the glottis being closed, there is high pressure in the lungs, the heart and large vessels, resulting in the drawing of the blood out of the pulmonary circulation into the heart circulation and through the arteries into the general circulation resulting in a rise of blood pressure, the veins outside the thorax being distended as seen in the veins of the neck and face, the heart being pressed on to such an extent that the heart sounds and the pulse may disappear.

In inspiration, and expiration into the spirometer the blood pressure curves are found to be altered. If the rarefied air is inspired, the blood pressure rises above the normal, and if an expiration takes place under similar circumstances. the blood pressure will fall, although it will continue above normal expiration. The rise in blood pressure arises from the effort required to inspire the air into the lungs, this effort being increased in connection with the other organs in the thoracic cavity, causing the blood to flow more rapidly through the pulmonary circulation. The air expired from the lungs into the spirometer tends to distend the vessels in the thoracic cavity and to assist the blood flow in the pulmonary circulation, when the vessels become gorged, and the extra-thoracic vessels become depleted, the blood pressure falls. If compressed air be inspired the inspiratory rise is diminished. If the air pressure is higher than the pressure of the elastic lung tension, the chest will distend without any muscle effort, resulting in a decrease inside of an increase of negative pressure, giving place to positive pressure. The heart and the other vessels in this case are compressed and the blood is forced out into the systemic circulation.

If expiration takes place into compressed air there is a temporary increase of blood pressure followed by a decrease due to the hindrance offered to the flow of blood through the heart to the lungs. These effects are noticeable in ballooning in which case there is added a complexity due to the pressure abnormally exerted upon the peripheral circulation. In the case of artificial respiration where bellows are used to force the air into the lungs, expiration taking place by the elastic recoil, after the lungs have been filled the capillaries are subject to the action of the positive pressure of the air in the lungs and the resisting force of the chest walls, the blood being drawn out of the lungs temporarily increasing the blood pressure to be followed by the decrease in pressure when the flow of the blood is retarded. When expiration takes place the pressure is taken away and the blood flow is promoted, a fall in the blood pressure existing until the vessels are filled, when there is a rise. If the air is expired out of the lungs the blood pressure rises on account of the distended condition of the lung vessels. Hence, in artificial respiration we find during inspiration that there is a temporary rise followed by a fall and during expiration there is a temporary fall followed by a rise in blood pressure. The respiratory system also bears a relation to other systems of the body. Deficiency in the oxygenation of the blood arouses the muscles in the alimentary canal to activity having also a material influence upon perspiration and possibly upon the other secretions. Respiration chiefly in connection with the respiratory center is also influenced by changes effected in the blood by the action of the skeletal muscles. Thus, the respiratory system is closely connected with all the bodily organs and may be said to act and react upon the system in general. Effort or work performed by the body results in depriving the blood of its oxygen and filling it with carbon dioxide. This change in the blood would affect the respiratory center and increase the activity of respiration to such an extent as to mark out the limits of deoxygenation and carbonization. This creates activity of the respiratory system which in its relation with the other systems makes provision for that metabolism which provides for the repair of this wasting condition.

Respiratory action is aided by cardiac activity, and hence, the two go hand in hand in preventing that collapse which is sometimes represented as want of breath and at other times as heart failure. Hence muscular activity depends not upon respiration only nor upon the blood circulation only, but upon the concerted action of both of these. The proper distribution of air implies the proper circulation of the blood. It may seem that respiration is more important for muscular activity but circulation is as important. This abnomally is represented in the common expression, breathless applied to an exhausted person, the real cause and condition being more probably want of heart action. The great difference between the endurance of persons is found to be due not so much to want of air represented by a panting, breathless condition, as to the incapacity of the heart to keep up with the quickened rate of respiration. As we said before there is a normal ratio between respiration and heart pulsation. Wherever this ratio is broken down, energy is impaired by reason of the impairment of some one of the two actions, lung action or heart action, most commonly the heart action.

There are therefore, two main elements in respiration. 1st, respiration proper and 2d, the circulation of the blood, the former bringing the air to the blood and the latter the blood to the air. Of course, there is implied in this, the normal condition of the blood, its richness in haemoglobin, that is, in red corpuscles, for upon this depends the volume of oxygen that is taken from the lungs into the blood. That this is so is evident from the fact that anæmic persons are very easily made breathless because of the lack of blood supply, and hence the lack of oxygenation through the blood. The force of the mechanism of respiration can only deliver to the blood and to the tissues the oxygen, the blood itself must take in and utilize it in order that it may be of value to the system.

Certain changes taking place in the circulatory system affect the respiratory system. The supply of blood furnished to the respiratory center may and often does materially affect respiration. If the blood flow is suddenly taken away from the medulla we find respiration attended with difficulty and sometimes accompanied by spasms. The supply of blood to the medulla through the basilar artery and its branches, if interfered with in any way either by increase or diminution of the blood flow may effect the respiration, similarly the supply of blood to the lungs if abnormal interferes with respiration. The arterialization of the blood is accomplished by the blood flow through the lung capillaries by being brought into close conjunction with the air in the air vesicles. If the pulmonary arteries become obstructed or if the valves of the heart fail to act properly or if the cardiac beat be weakened the circulation of the blood from the pulmonary vessels to the heart is interfered with and hence, the amount of oxygen carried by the blood to the different tissues of the body is lessened on account of the decreased blood flow. In this way the blood circulating is less than normal and it is less arterial than normal, the nerves and muscular tissues being thus deprived of a chief part of their nutriment, the oxygen. This deficiency of oxygen manifests itself in connection with the medulla by dyspnœic conditions, the difficulty of respiration associates with this condition, sometimes leading to the more normal pulmonary circulation. The blood circulation and consequently the tissue nutriment thus depends to a large extent upon the normal respiratory action.

MODIFICATIONS OF THE THE NORMAL RESPIRATORY MOVEMENTS.—The chief function of the thoracic expansion and contraction is to secure adequate lung ventilation. There are subsidiary functions however, discharged by these respiratory movements spoken of in Physiology as special respiratory actions. Some of these respiratory actions are volitional and some of them are spasmodic. Respiration in man is used as a means to give vent to the feelings and emotions. The volume of air expired from the chest is also used to expel certain substances from the upper air passages in this way providing for a clearing of these air passages so as to aid the normal respiration. Hence, we find certain peculiar acts which are not peculiarly respiratory, although they assist in the general economy of nature. These actions are all reflex, the movements being determined by some form of stimulation. 1st, COUGHING. Coughing consists of a deep inspiration followed by the partial closure of the glottis, and a sudden expiration during which the glottis opens forcibly and a volume of air is forced through the upper respiratories, in some cases foreign substances being expelled also. Coughing represents not only an abnormal state of the respiratories, it may also indicate an irritation of distant parts of the system, such as the stomach, liver, spleen, uterus. These are sometimes called sympathetic coughs. Coughing is either a reflex or a voluntary action. The afferent impulses are usually carried by the superior laryngeal, as for example, in the case of an irritant substance found in the larynx. Stimulation may also arise in connection with the vagus branches to the bronchial tubes and to the stomach. Stimulation, also, of the sensory nerves of the skin may produce coughing, as in the case of cold drafts of air. SNEEZING represents a deep inspiration followed by a strong expiration. This expiration being strongest in its passage through the nasal cavity, the opening from the pharynx into the mouth, being closed by the contraction of the pillars of the fauces and the falling of the soft palate. Sneezing is generally a reflex action, resulting from the irritation or the stimulation of the nasal branches of the fifth pair of cranial nerves. In the case of sneezing produced by a brilliant light the optic nerve is the afferent nerve. When the act itself is coming on, manifested as it may be by premonitary signs, it may be stopped by the firm pressure of the finger against the upper lip, or by the close pressure of the lower lip against the upper lip. In LAUGHING there is an inspiration succeeded by a number of spasmodic and interrupted expirations, the glottis being opened and the vocal chords vibrating freely at each expiratory movement. The expirations in the case of laughter are less forceful than they are in the case of coughing. The mouth is opened and the muscles of expression give to the face the facial characteristic expression.

In the case of CRYING the movements of respiration are somewhat similarly modified as in the case of laughing, modified, however, by certain muscular movements. It is this that makes it so easy to pass from laughing to crying and from crying to laughing. There are differences however in the rhythmical movements and also in the facial expressions. Accompanying crying there is, of course, a secreting process which produces the tears and also in laughing if laughing is carried to a large excess. In SOBBING which sometimes follows crying there is a series of convulsive inspirations, the glottis being partially closes so that little, if any, air passes into the chest. In sighing, on the other hand, there is a deep and long inspiration largely through the nasal cavity followed by an expiration of shorter duration. YAWNING is also a deep inspiration during which the mouth is opened, usually accompanied by muscular contraction of the shoulders and of the back

and by the lowering of the under jaw. These movements are normally followed by short expirations. In SNORING the mouth is opened and air freely entering, passing in and passing out causing the palate and the uvula to vibrate freely. During inspiration the sound is very marked and it may be absent during expiration. In GARGLING the throat the liquid used is sustained between the palate and the tongue the air being forced through the fluid producing the characteristic bubbling sound.

SECTION VI.—Changes in the Air During Respiration.

It is only in comparatively recent times that the necessity of fresh air has been recognized as one of the necessities of life. Older writers did not recognize the importance of respiration at all. It was supposed that by the inbreathing of air the air passed into the heart itself to cool the heated condition of the blood and to arouse the spirits. The idea of cooling the blood by respiration was the prevailing idea until the 17th century. It was in the 17th century that Malpighi discovered the existence of the air cells in the ungs. It was at this time that the air was found to be necessary to life and that exchanges take place between the air and the blood. Following this we find experiments that indicated the variation in the air breathed as a cause of life, muscular activity and healthy or abnormal life conditions. Following these was the discovery of carbonic acid and oxygen, the one given off from the body and injurious to life, the other taken into the body and beneficial to life. At this point the atmosphere was analyzed and found to contain two constituent gases varying in breathing and produces varying results when breathed. At the beginning of this century expired air was found to have lost oxygen, to have gained carbon dioxide and aequeous vapor, and to have become hotter. Many researches have been made with the subject of discovering the amounts of these substances. The method used has been to draw through a chamber in which an animal is placed a continuous current of air whose amount and composition are known.

If a certain quantity of air deprived of CO_2 consisting only of O and N passes through such a chamber some O is consumed and some CO_2 and aqueous vapor are given off. If the air is pulled in through tubes containing substances that will absorb CO_2 and the vapor is then the amount of CO_2 and vapor will be represented by the increase in the weight of the contents of the tubes. By such experiments as these various physiologists have found that about 500 C. C. at 30 cubic inches of air are taken into the lungs at each inspiration. If we calculate 15 to 17 respirations per minute this will represent about 1,080,000 C. C. in 24 hours of air inspired. While the air is in the bronchial tubes the tidal air makes certain inter-changes with the air inside these vessels. In an ordinary inspiration 30 cubic inches or 500 C. C. of air rushes into the upper part of the pulmonary passages pushing, as it were, before it the air already in the lungs which is called the stationary amounting to about 200 or 300 cubic inches. Diffusion now takes place between the new or tidal air and the stationary air, oxygen diffusing from the former downward into the letter while carbon dioxide diffuses from the latter to the former upward. At the next expiration following the inspiration 30 cubic inches or 500 C. C. of air is expelled. 170 C. C. of this is estimated as part of the air taken at the immediately preceeding inspiration, the remaining 330 C. C. being vitated air returned from the lungs. Hence, of the 500 C. C. taken into the respiratory tract by an inspiration, 330 C. C. remain in the pulmonary system gradually passing by diffusion down to the air cells and reaching these in the time occupied by about five inspirations. In the expired air the first portions expelled are atmospheric air while the portions of CO_2 and aqueoua vapor gradually increase in the air that is expelled in the latter stages of expiration. The temperature of expired air varies but it is usually slightly above that of the inspired air. When the atmosphere is about 20°C the temperature of expired air in the mouth is about 34°C and in the nose 35.5°C if the temperature of the air sinks low, expired air falls slightly, for example, at 7°C the expired air is about 29°C. If the air temperature is high the expired becomes cooler than the inspired air, for example, at 40°C the expired air is 37°C. The expired air usually follows the blood temperature depending on the relation of the blood temperature to the atmosphere and the breathing rate, the change taking place not in the lungs but in the upper respiratories.

The average composition of atmosphere is about as follows :

In 100 volumes we have oxygen 20.90, nitrogen 78.80, CO_2 .05, but, of course, there is a percentage of vapor H_2O about .85. There are also slight quantities of nitric acid, carburretted hydrogen, ammonia, and also organic and inorganic minute substances. The aqueous vapor depends on the temperature, being higher with a higher temperature. The moisture, like the heat, is imparted not in the lungs but in the upper respiratories. Respiration, therefore, is influenced by the air temperature and also by the air pressure. When the temperature is high an air containing less oxygen is breathed. In order to counterbalance this loss of oxygen the respirations become deeper and also more numerous. The difference between the inspired and the expired air is an important element in connection with respiration.

(1). Inspired air has O 20.81 per cent; in the expired air that amount of oxygen is decreased to about 16.03. (2). The nitrogen is about 79.00 per cent in the inspired air, increased to about 79.50 per cent in the expired air, (3). The CO_2 varies in the inspired air from .04 to .05. In the expired air it increases to 4.38 sometimes to 5. (4). H_2O varies in the inspired air also in the expired air with the temperature. In the expired air the H_2O not only varies with the temperature but also according to the saturation of the vapor with certain substances containing a quantity of organic matters which give the odor to the breath and some of which are poisonous. (5). In the inspired air we find NH_3, the organic proportion varying with situation, etc. An atmosphere containing one per cent of CO_2 is far less hurtful in respiration than one containing the same portion of CO_2 added as a result of respiration of the living organisms in the atmosphere. In one breath, for example, the air has more CO_2 and less oxygen at the close than at the beginning of the breath. Hence, if the breath is held for a long time, that is, if we have a pause between inspiration and expiration the amount of CO_2 is greater in the expired air. In the case of expired as compared with inspired air we notice four or five different points. First of all, the expired air contains almost ~~almost~~ five per cent less of oxygen. 2d, It contains 100 times more of the CO_2. 3d. It contains about ½ per cent more of nitrogen. 4th. The expired air is generally hotter than the inspired air. The temperature of expired air is normally about 37°C. 5th. The expired air sometimes contains ammonia, carburretted hydrogen, and also the volatile gases. The volume of air expired at any one respiration is the same normally as the volume that is inspired.

The volume of expired air however, may be slightly greater than the volume of inspired air, but this is due to the expansion of the expired air resulting from an increased temperature. If both volumes, the volume of inspired and expired air are measured at the same temperature, and at the same pressure, the volume of the expired air is slightly less than the volume of the inspired air, the diminution in volume amounting to 1-40 or 1-50 of the whole volume. This diminution is due to the fact that all the oxygen taken in during inspiration does not appear in the expired air as CO_2. Some of it having been retained and entering into the formation of other combinations within the body. It is estimated by the Physiologists that from 800 to 2,000 grams of H_2O are given off by the expiration process in 24 hours. It is believed by Physiologists that the larger proportion of this comes from the moist walls of the upper respiratories. This conclusion is reached from the fact that dry air when it is inspired, becomes quickly moistened in passing through these respiratory passages. This gives us these results: 1st, that the air expired is saturated with vapor, the amount of water which a volume of gas can take up as aqueous vapor, depending on the temperature. The higher the temperature the larger the amount of aqueous vapor being taken up. The expired air is then saturated with this aqueous vapor and this saturation takes place, not in the lungs, but in the upper respiratories. 2nd. The volume of expired air is smaller than the volume of inspired air to the extent of about 1-40 or 1-50 of the volume of inspired air. It is estimated that 700 grams of oxygen are absorbed, and 900 grams of CO_2 in weight are eliminated in twenty-four hours. This amount of CO_2 represents 244 grams of carbon, and 656 grams of oxygen, so if we subtract this from the 700 grams absorbed, we have left 44 grams of oxygen disappearing through the body. We must consider, accordingly this fact that CO_2 is not only eliminated from the body by the lungs, but also to a slight extent through the skin, the estimate being that about 1-140 of the entire volume of CO_2 eliminated from the body is eliminated through the skin. These numbers, of course, are subject to wide variation, depending upon the conditions of the individual, also upon the condition of the air that is breathed.

Foster states that in his own observation the CO_2 has varied from 686 to 1285 grams, and that the oxygen has varied from 594 to 1072 grams, these variations depending largely upon nutrition. The amount of CO_2 that is eliminated is increased by rapid and deep breathing. After a single breath the air is poorer in oxygen and richer in the CO_2; hence, if the breath is held for a long time, there is a pause between the inspiration and the expiration and the CO_2 is increased in the air that is expired. The relative proportions of oxygen taken in and the CO_2 eliminated vary in the proportions between these being represented in what is called a respiratory quotient. This respiratory quotient is found by dividing the variation in the CO_2 by the variation in the oxygen, that is $\frac{4.34}{4.78}=.901$. Hence when a volume of oxygen is lost we find this amount .901 of a volume of the CO_2 gained. This variation is less during sleep. It is greater in middle age persons than in young persons and in old persons. Muscular activity and an increased amount of carbon in the diet will also increase the amount of CO_2 excreted. The principles of ventilation demand a proportion of oxygen to CO_2 that is the reason why the Physiologists have estimated this respiratory quotient so as to have an adequate foundation for the principles of lung ventilation. When a number of persons placed in a limited space with little or no ventilation the oxygen is diminished and the CO_2 is increased also the aqueous vapor and the organic substances are increased. If an animal is placed in a limited space without any air renewal the air gradually loses its oxygen and becomes more fully charged with CO_2. If the proportion of oxygen does not fall below 15 per cent the respiration remains normal. From 15 to 7 percent the respiration is liable to become labored, inspiration and expiration. From 7 per cent to 4 per cent it becomes very difficult. If it falls under four per cent it is liable to result in asphyxia. When the body dies the blood contains oxygen and this oxygen is absorbed into the tissues of the body. The quickness of asphyxia proving fatal depends upon the amount of oxygen in the limited spaee in which the animal lives. When an animal, for example, is placed in a confined space the animal accommodates itself to the limited amount of oxygen and it will live in an atmosphere so saturated with CO_2 as to cause the immediate death of another animal put in the same chamber. Claud Bernard, for example, placed a bird under a glass globe and a few hours later he put into the same globe another bird; the second animal died in a few minutes in convulsions while the first animal survived for several hours and continued to respire. In addition to the absence of oxygen we must remember the presence of CO_2.

Air that is suitable for breathing should not contain more than .07 per cent of CO_2. Other gases are given out from the body which give to the atmosphere what is commonly called the stuffy character arising from the lack of ventilation. This vitiation is increased where coal oil or gas is used causing the oxygen to be consumed and also filling the air with many the dangerous products of combustion. Difference of opinion exists as to the nature and action of the toxic substances in vitiated air, depending to some extent upon the place, the persons and their circumstances, which are individual to the person or to the place in which the person is found. In addition to the CO_2, expired air contains, as we have said, other substances which render the air impure. Small quantities of ammonia have been found even in the air taken directly from the air passages. By condensing the expired air into a cooling receiver the aqueous vapor has been found to contain organic substances, which by the presence of micro-organisms from the air inspired, causes organic decomposition. These substances in this condition produce in part the odor of the breath. Some of these substances are poisons, either on account of some poisonous substance directly in the air expired or on account of the decomposition of organic matter. The expired air is sometimes found to contain ptomaines. The presence of these poisous substances make the air very injurious to the system. This poisoned air is due more to these substances than to the presence of CO_2, these matters accompanying the CO_2 and being usually measured by the proportion of CO_2 found. Hence, the problem of lung ventilation is not only one of providing for sufficient fresh oxygen or that it be comparatively pure, but also the providing air comparatively free from CO_2 and accompanying organic substances which constitute the impurities of the air for breathing purposes.

The object of ventillation is not only to introduce fresh air, but to dilute the CO_2 so as to restore it to its normal condition. It is estimated that for an efficient ventillation, taking into account the size of the person and size of the room and the activity of the person, supposing that an individual gives off 900 grams of CO_2 daily and that CO_2 is kept at the average of .07 volumes per cent, 2,000 cubic feet of fresh air should be supplied for each individual per hour. Pure air contains 4-10 volume in a thousand. If it contains one volume per thousand it is impure and gives off an odor. In cases of muscular activity more than this would be required on account of the increased elimination of CO_2. When persons are limited to certain apartments every person should have a thousand cubic feet of

space, and the floor-room should be at least 1-10 of this and fresh air should be introduced hourly. In the case of large rooms where a number of persons meet, for example, lecture rooms, this renewal of air should be very frequent. The lung capacity represents the total amount of air that can be forced into the lungs by the most forced inspiration. The bronchial capacity is the capacity of the bronchi and trachea, estimated about 8½ cubic inches.

Alveolar capacity represents the amount of air that can be accommodated in the small air passages, the alveoli being smaller during expiration than during inspiration. During normal expiration it is about 120 cubic inches, and during normal inspiration about 150 cubic inches. These are distinguished from the vital capacity which represents the quantity of air that can be expired by the most powerful expiration.

The ventillation of the lungs artificially is of considerable importance. The trachea is exposed and a tube inserted into it through which air is forced periodically into the lungs by the use of bellows or the pump. Some instruments not only cause air to be inspired but alternately to be expired from the lungs. The periodic inspiration is called positive ventillation. The expiration is called negative ventillation and the two processes alternated compound ventillation. In the human subject these methods are very dangerous as the continuance of positive ventillation produces cerebral anæmia, fall of blood pressure and body heat. Hall and Sylvester have described the most commonly adopted methods. Hall's method is to put the patient on his face, supporting the chest upon a pillow, then turning the body gently a little beyond the side position then quickly turning the body on the face, repeating this process about fifteen times per minute. Raising the body on the chest the air is expired; when the body is raised on its side the air is inspired freely. At each turn of the body upon the face, pressure is brought to bear upon the back below the shoulder blades, the pressure being removed before turning the body again on its side. According to Sylvester's plan the patient is placed upon his back on a solid flat surface with the head inclined slightly downward and the feet upwards, a pillow or small support being placed beneath the shoulder blades. The tongue is then pulled forward beyond the lips and by the use of an elastic band around the chin and elongated tongue it is kept in this position. From above the patient's head the arms are seized just above the elbows, and are then drawn gently above the head and kept in this position for 2 or 3 seconds. Then the arms are turned and pressed closely against the sides of the chest for two or three seconds. These movements are repeated about 15 times in a minute until active respiratory action takes place in the body.

SECTION VII.--Changes in the Blood During Respiration.

As the blood leaves the right ventricle it is venous. When it is brought back to the left auricle it is arterial, of a bright scarlet color. The question that arises, is: "What is the difference between arterial and venous blood?" In passing through the pulmonary capillaries, that is, during pulmonary respiration the blood changes from a dark purple to a bright scarlet color. In other words it loses CO_2 and gains oxygen. In passing through the systemic capillaries in tne various tissues of the body, that is, during internal respiration, the reverse process takes place, the blood loses its oxygen and gains CO_2. Hence, the blood changes from a bright scarlet color to a dark purple. The exact nature of these changes in the pulmonary alveoli is not easily determined. It would seem, however, that the pulmonary epithelium does not perform any particular function of absorption or excretion in this process and that the interchange between the gases of the blood and the gases contained in the pulmonary alveoli is determined simply by the law of partial pressure. Oxygen passes from the air cells into the blood because the tension of the oxygen in the former is greater than the tension in the latter, that is, the blood which reaches the lungs through the pulmonary artery, while the tension of the CO_2 in the blood is greater than the tension of the gases in the air-cells. Oxygen is passing into the blood both in inspiration and expiration, especially during inspiration. CO_2 is also escaping from the blood in inspiration and in calm expiration, but not in deep expiration. The venous blood becomes arterial if it is exposed to the atmosphere or if it is mixed with oxygen, whereas arterial blood will become venous if it is kept in a closed vessel or subjected to a current of nitrogen or of hydrogen. The chief difference therefore, between the venous blood and the arterial blood is in the amount of oxygen and the amount of CO_2 contained in each. The other differences depend upon this main difference. The ordinary air pump is not sufficient to extract the gas from the blood.

Pfluger has invented a mercurial pump which is a convenient arrangement for the extraction of the gases from the blood. This pump consists of a long barometric tube, the upper part of it opening into a mercurial globe with the upper end of which there are connected two tubes, the one tube vertical and the other tube horizontal—the vertical tube communicating with the air and the horizontal tube opening into a glass receiver in which the blood is placed. At the openings of these two tubes into the globe there are stopcocks.

From the lower end of the barometric tube a rubber tube passes into another globe of larger capacity than the first globe. This larger globe may be raised and lowered by means of a crank arrangement, the object of this arrangement being to extract the air out of the blood that is in the receiver very rapidly. After the air has been removed the blood is put into the receiver, out of which the air has been removed. The blood gases under a minimum pressure then escapes. These gases pass into the small globe from which they are driven through the vertical tube and then gathered in the graduated tubes. By means of this graduation the amount of gas per volume of blood is easily measured. The total amount of gas being found the amount of each gas may be easily estimated by means of volumetric analysis. The percentage of the gases obtained from the two kinds of blood measured at 0°C and 760 mm. of mercury barometric pressure are found to be as follows:

In 100 volumes of blood.—In the arterial blood we find 20 per cent of oxygen, 39 to 40 per cent of CO_2 and 1 to 2 per cent of nitrogen. In the venous blood, 8 to 12 per cent of oxygen, 46 per cent of CO_2 and 1 to 2 per cent of nitrogen. That is, the variation between the venous blood and the arterial blood is wholly in the O and the CO_2, the nitrogen is invariable. This means that arterial blood as compared with venous blood contains from 8 to 12 per cent more of oxygen and about 6 per cent less of CO_2. Some Physiologists say, 8 per cent less of CO_2. In the case of arterial blood there is very little variation throughout the arterial system, while in the venous blood differences occur according to the location of the blood vessels. For example, venous blood from an active secretory gland is almost identical with the arterial blood, while if the gland is inactive the blood is characteristically venous.

Lavoisier, found that respiration consisted of the combustion of carbon and of hydrogen, the blood furnishing the combustion materials and the air furnishing the oxygen. He admitted, however, that CO_2 is formed directly in the lungs, or even in the blood vessels wherever the oxygen can come into contact with the carbon found in the blood. His successor, Lagrange, believed that oxygen is dissolved in the blood combining with carbon and hydrogen to form CO_2 and H_2O. These are liberated, the CO_2 and H_2O—in the lungs, but the CO_2 production does not depend upon the oxygen, that is, the oxygen that is supplied by or in the lungs. If an animal, for example, is placed in a chamber with nitrogen or hydrogen in place of the atmosphere, the CO_2 is produced to the same extent as in the normal atmosphere. The CO_2 also is found in the body, this CO_2 being supposed by some Physiologists to be stored in the capillaries, and from these capillaries to be passed into the lungs.

Two theories of respiration have been advanced by Physiologists in recent years, to account for the interchanges between the blood and the air. 1st, the combustion theory. This theory ascribes to the process of combustion in the lungs the production of the CO_2 and H_2O aqueous vapor; and 2d, the secretory theory. This theory denies that there is any combustion process in respiration, whereas, the oxygen becomes absorbed in the lungs and then becomes diffused through the other tissues of the body, the CO_2 being secreted in these, absorbed into the blood and then carried to the lungs and given off in the expired air. Recent investigations in connection with the gases of the blood and the temperature of the blood as found in the right and left sides of the heart have given predominance to the last theory which now prevails in the field of Physiology. The older Physiologists rejected the secretory theory on account of the fact that no proof existed of free oxygen or free CO_2 in the blood. The same obstacles met those who defended the secretory theory because if the process of interchange takes place in the blood then certain free gases must be found in the blood. And hence, so long as the gases of the blood remained unknown the combustion theory prevailed. Priestly in the 17th eentury 1st emphasized the change in color of the blood as being due to oxygen from the air, the blood becoming purple under the influence of CO_2. Magnus in the beginning of the 19th century invented a mercurial air pump by the use of which he could exhaust a receiver so that introducing the blood into the vacuum CO_2, O and N. could be liberated from the blood. To him we are indebted for our systematic knowledge of the gases of the blood and he is really the founder of the secretory theory of respiration. Gaseous masses unlike the solid and the fluid masses have no form hence gases are said to be formless. These gaseous masses consist of a large number of molecules always tending to separate from one another on account of mutual repulsions. Hence, if two gases meet they will easily intermingle until an exact quantity of each gas enters into the combination. The molecular repulsion is called the gas pressure or the gas tension. The physical law bearing upon gas is that the greater the molecules the greater the tension. Hence the law of gases is that the pressure is in inverse proportion to the volume. If two gases are suspended or separated from one another by a slight membrane, they will mix, passing through the membrane with a speed in proportion to the density of the gases. The fluids also absorb the gases. For example, if some amonia gas is placed in contact with water, the water wlll rapidly absorb the amonia gas.

The higher the temperature of the water is raised, the fluid absorbs less of the gas, and when the fluid reaches boiling point no gas is absorbed, the cause of this being that the fluid becomes gas. The co-efficient of absorption in the case of a fluid for a gas is, according to Bunsen, the number representing the gas volume reduced to 0°C and at 760 mm. Barometric pressure taken up by one volume of the fluid. The volume of gas, then, that is absorbed does not depend upon the pressure but the weight of the gas absorbed rises and falls in proportion to the pressure. If an atmosphere above a fluid consists of two or more gases, absorption will take place in proportion to the pressure each gas would have if alone, in the place of the mixed gases. This pressure in the case of two or more gases is called the partial pressure of gas, according to Bunsen. The partial pressure, therefore, depends upon the volume of each gas in the combination of gases. Each gas forming an element in a mixture exerts a pressure equal to its proportion of the mixture. For example, atmospheric gas is under the pressure of 760 mm. In air we find 20 volumes per cent of O. and N. 79 volumes per cent; therefore, the partial pressure of O would be 760 times 20.81 divided by 100, this would equal 158.16 mm. represent the partial pressure of O. In the same way, the partial pressure of N. would be 760 times 79 divided by 100 representing about 600.04 mm. of mercury. The partial pressure CO_2 would be found in the same way, 760 times .04 divided by 100 would give us about .304 as the partial pressure of CO_2. If above a fluid containing a gas like CO_2 there is another gas, say the atmospheric gas, as CO_2 is very small in the atmosphere, its tension is O, the CO_2 will escape from the fluid until there is an equilibrium between the CO_2 in the fluid and in the air, that is, till CO_2 tension in the air is equal to CO_2 tension in the fluid. This tension of the gas represents what we call partial pressure represented in mm. of mercury, a tension exerted by the gas of the atmosphere when there is no diffusion between the gas in the fluid and the gas in the atmosphere. By using these results in connection with arterial and venous blood we find (1) that both kinds of blood contain O, CO_2 and N. (2) the difference between arterial and venous blood is in the amount of O and CO_2, (3) the gases are dissolved in the blood so that respiration is simply a process of diffusion, CO_2 passing out and O passing in according to the law of pressure. Three important elements enter into the process of respiration, (1) the inspiratory and expiratory movements causing a partial mixture of the air, (2) subsidiary movements such as the heart pulsations and (3) the diffusion of O and CO_2 depending upon the law of partial pressure. The venous blood containing CO_2 at blood temperature and with a certain pressure enters the pulmonary capillaries distributed over the walls of the alveoli in the lungs. These air cells are filled with air at a certain pressure and temperature. If the pressure of CO_2 in the blood is greater than that of CO_2 in the air vescicles, CO_2 will pass from the blood till equilibrium is restored. Similarly if the pressure of O in the blood is greater than that in the air cells O will be absorbed until equilibrium is produced. This is true if the gases are simply dissolved in the blood. But the gases exist, as Liebig pointed out, in the blood rather in a state of loose chemical combination, dissolution taking place by lessening the pressure in the vacuum or by other gases. As a result, the amount of oxygen absorbed does not vary exactly with the pressure but decreases in the case of temperatures below the atmospheric pressure and increases in pressures above atmospheric pressure.

This fact is proved by the observation that blood serum does not absorb much more oxygen than does water, (blood at 30° C containing only 2 vol-

umes per cent of O, if the O is dissolved in the fluid,) and defibrinated blood absorbs oxygen, the amount depending not upon the pressure but upon the amount of the pure haemoglobin that is found in connection with the blood. In the same way CO_2 is in a state of loose chemical combination, only a small quantity being subject to the law of partial pressure. This, of course, would be explained on the secretory theory, that the pulmonary membrane is actively engaged in the secretory process. The gases of the blood, in this case, instead of existing in a simple solution, are largely in combination with the blood so that its escape from the blood is by a process of dissociation. Berzelius has shown that 100 volumes of water absorbed at a given temperature and pressure three volumes of oxygen. 100 volumes of blood serum absorbs 3 1-10 volumes of oxygen, and 100 volumes of blood will absorb 9 6-10 volumes of oxygen. There must be, therefore, something in the blood which assists or causes the absorption of such a proportion of oxygen. The haemoglobin has been found to play an important part in respiration, and as we will see later, this haemaglobin is the element in the blood which absorbs oxygen according to the law of partial pressure. The coloring matter of the blood is found to exist in two states, the differences being represented by difference in color. These two states represent differences in oxidation. This is found in connection with the spectroscope. Only a small quantity of O is absorbed according to the law of partial pressure, the great mass of oxygen being in combination with the haemoglobin. On the other hand the CO_2 seems to be associated with some substances in the blood plasma and that its dissociation is connected with some substance in the red corpuscles. The haemoglobin when it is united with oxygen is called Oxyhæmoglobin. Hæmoglobin is an amorphous powder, or crystal line, very soluble in water. Crystallized hæmoglobin readily absorbs and holds in combination a quantity of oxygen equal to that found in a volume of blood containing the same amount of hæmoglobin. This gives us, then, a special function for the red corpuscles of the blood in connection with respiration. The hæmoglobin of the blood in the pulmonary artery absorbs oxygen, becoming oxyhæmoglobin, carrying it to the tissues where the oxyhæmoglobin is reduced. Thus the coloring matters of the red corpuscles are constantly carrying the oxygen from the lungs to the tissues, the association and the dissociation taking place without destroying the hæmoglobin. In regard to the CO_2 our knowledge is less definite. The greater part of the CO_2 is found in the blood plasma. Defibrinated blood, for example, yields only a little more CO_2 than the serum of the blood to the same amount. Blood serum in a vacuum yields about 30 volumes per cent of CO_2. If a mineral organic acid is added to the serum the per cent will be very small, amounting only to about 6 volumes per cent. Defibrinated blood, on the other hand, will yield 40 volumes per cent of the CO_2 the yield of a little more CO_2 from the same amount of defibrinated blood than in the case of the blood serum, being supposed to be due to something in the defibrinated blood which acts the part of an acid. There must be some chemical substances for the absorption of the CO_2 of the blood. Some Physiologists have suggested plasma albumin. As yet, however, this subject is not fully investigated by the Physiologists so that we can say definitely what substance causes or produces this absorption. In all probability what takes place is as follows:

The air inspired is in some way separated in the air cells of the lungs, by the fine epithelial cells and the endothelial cells of the pulmonary capillaries from blood circulating in them. This interchange is through a fine porous membrane. The oxygen, as we have said, is loosely bound to the hæmoglobin of the corpuscles; hence, the law of diffusion applies only in so far as it must pass into the plasma of the blood so as to reach the corpuscles. The corpuscles of the venous blood return from the tissues with reduced hæmoglobin. Oxygen enters the plasma from the air and the hæmoglobin at once takes up a fresh supply of this oxygen. If the oxygen were not loosly combined with the hæmoglobin, the oxygen alone would be absorbed, and the amount that is absorbed would depend upon barometric pressure at the time, varying at different times with the variation in the pressure, and only with the variation of the pressure. If this is true, such variation would, materially, interfere with the conditions of health. This is evident from the fact that in high altitudes as well as in deep mines, the health of thn blood is not materially affected, although the pressure rises and falls considerably for the oxygen exists in a loose chemical combination independent of the law of partial pressure. In the case of CO_2 it is found, as we have said before, almost exclusively in the blood plasma, a small part of the CO_2 being absorbed, and a large part chemically bound either with sodium carbouate or with the acid of sodium carbonate and sodium phosphate. In the air CO_2 is found only in small traces. The air of the lungs is never wholly expelled, some of the air that is rich in the CO_2 always remaining in the lungs. Hence, the mixture of the inspired air with the air of the air vescicles makes the latter air rich in oxygen and poor in the CO_2, although there is more CO_2 than in atmospheric air.

The pressure of CO_2 in the venous blood is found to be almost 50 per cent more than that of the air cells. CO_2 then passes from the blood into those air cells till equilibrium is attained. Before this is attained, however, expiration begins and expiration has driven out a portion of the air so that the pressure of the CO_2 again becomes less than the blood. During expiration and the pause following it, still further elimination of CO_2 takes place. In expiration, then all the air is not driven out of the lungs for if it was so then no diffusion could take place during expiration and the pause following it, Diffusion could only be possible during inspiration. The separation of the CO_2 in this case from the pulmonary blood would be incomplete, changes being found only in the rapidity of the process which would materially interfere with the respiratory changes in connection with the blood necessary to carry on the normal process of respiration.

Having discussed these changes that take place in connection with the gases of the blood it is necessary now to inquire what are the causes of the changes that we have observed. The absorption by oxygen of the blood, as we have said, does not follow the physical law of simple absorption on the basis of pressure. It is suggested, as we have said, that oxygen is in combination with some substance in the blood, which retains its association when pressure is lowered until a certain point is reached, when dissociation takes place, no appreciable dissociation taking place till this point is reached. After this point is reached dissociation takes place very rapidly. We have seen that the substance with which the oxygen is closely associated is the hæmoglobin of the red corpuscles. Hæmoglobin when dissociated from other substances is an amorphous powder or a crystal in solution. The peculiar relation between the hæmoglobin and the stroma in the normal blood prevents the hæmoglobin from being dissolved in the serum. In order to get the hæmoglobin this relation between the stroma and hæmoglobin must be broken. By the addition of distilled water or ether, or chloroform, the blood will be rendered lakey. By the removal of the alkaline serum the

hæmoglobin is given up in the solution. If dilute acetic acid be then added the alkaline reaction is reduced, and if alcohol is then added to the solution to the extent of one-fourth of the solution and if the solution be apart at 0° C the hæmoglobin in the solution will be crystalized. These crystals bsing separated by the process of filtration. These crystals vary in the case of the blood of different animals. These hæmoglobin crystals are said to contain, for example, in the case of the dog's blood of C 53.85, O 21.84, N. 16.17, H. 7.32, S. .39, and iron .43. Iron is found in small quantities and it is a characteristic element of the hæmoglobin. If these crystals are examined microscopically they are found to possess the bright scarlet hue of arterial blood, in masses they are much darker. If these crystals are placed upon a slide with a few drops of distilled water the same arterial color may still be observed. This same solution placed in front of the spectroscope absorbs some rays of light, two very marked absorption bands being observable. These absorption bands are characteristic marks in the identification of blood. The intensity of the bands depending upon the strength of the crystaline solution. Under the micro-spectroscope the same marked appearances are presented by the crystals of hæmoglobin. If these hæmoglobin crystals are placed in the mercurial pump vacuum there is a change in color and the oxygen is driven off. This indicates that there are two volumes of O in the hæmoglobin, (1) the oxygen found in the molecular composition of hæmoglobin, and (2) a quantity loosely combined with hæmoglobin and therefore easily dissociated under the influence of pressure. If this second quantity of O is dissociated the change of color takes place, the crystals being dark purple in the thick parts and greenish in the thinner parts at the marginal edges. In the case of a solution of hæmoglobin we find the same quantities of O which may be liberated by the low pressure of the air pump or by passing through the solution a stream of hydrogen, resulting in the change of color from the bright scarlet to the deep purple. When this reduced solution of hæmoglobin is examined spectroscopically the two absorption bands formerly seen in the unreduced solution give place to a single absorption band wider and more faint in color, the single band lying about midway between the two bands of the unreduced solution. If this hæmoglobin solution which has been deprived of all the loosely combined O is exposed to the atmosphere, O is at once absorbed. The amount of O absorbed if there is an atmosphere filled with O amounts to the full combination in the hæmoglobin as found in the blood, each gram of hæmoglobin absorbing 1.59 of O. If the full complement is taken up the hæmoglobin changes from the dark purple color to the bright scarlet hue. In these changes we have from the standpoint of physiological physics the explanation in part at least of the changes taking place in the blood in connection with respiration and an explanation of these changes of color in venous and arterial blood. When the venous blood leaves the right ventricle there is too small a proportion of hæmoglobin for the red corpuscles. Hence the dark color of the blood. In ordinary venous blood when examined after dilution under the spectroscope the two characteristic absorption bands are observed. The hæmoglobin is only partly reduced in this condition, there being a quantity of loosly combined O. The venous blood only loses this O after death resulting from asphyxia when the venous blood becomes characteristically venous, the hæmoglobin being reduced and exhibiting the one broad absorption band instead of the two. When the venous blood goes through the lung capillaries it takes up O from the air, the red corpuscles being oxyhæmoglobinized, that is, almost completely saturated with the

O and changing to the bright scarlet color. When the blood goes out from the left ventricle and enters into the tissues through the capillaries this oxy- hæmoglobin once more loses its O and again becomes venous, the hæmo- globin being the oxygen carrier. Hence the chief difference between the arterial and venous blood is the presence in the former and the absence in the latter of oxygen in combination with hæmoglobin.

In addition to this there are subsidiary causes that enter into the change. By the swelling of the corpuscles, it loses to a certain extent its power of refraction; hence the number of rays that pass into and are ab- sorbed within it, multiply beyond the number of those that are reflected from the marginal surface. This swollen condition may be due to water or to the presence of CO_2; hence the presence of water or CO_2 tends to in- crease the venosity of the blood. On the other hand, the presence of salts tends to contract the corpuscles reducing this venous condition. The pe- culiarity of the combination of O and haemoglobin is its loose character, that is, the readiness with which the association and dissociation takes place without destroying the integrity of the haemoglobin. The haemo- globin will associate with other gases in the same way. If C O is brought into contact with haemoglobin by causing diffusion, the color is changed to a bluish hue, the association taking place between C O and haemoglobin, although not so freely as with O. C O is sometimes used for this reason, to drive out O from the blood so as to measure the volume of O present in the blood. It is this that makes C O so dangerous when inhaled, driving out the O from the blood, the reduced and unreduced haemoglobin freely associating with C O in the venous blood, producing a bright cherry color in the blood after death. This C O haemoglobin cannot be used in respira- tion because it cannot absorb O, although it exchanges its C O for O very slowly. This produces death by suffocation on account of the absence of O, the blood not becoming very venous but bright colored on account of the presence of C O. The diffusion of haemoglobin takes place with diffi- culty on account of its proteid character. Haemoglobin is a colorless pro- teid associated with a coloring substance, haematin, of a brownish red color. If a solution of haemoglobin is heated, coagulation takes place, the color of the coagulum being brown on account of the presence of haematin. This haematin when freed from combination with globin is a brownish amorphous powder with a bright metallic polish. When iron is extracted under the influence of sulphuric acid it still retains its color but ceases to combine with O, indicating that the iron element is an important constituent of haemoglobin, in the respiratory function, although it is not known what part it plays in respiration.

After the decomposition of blood the hæmoglobin is changed into methæmoglobin, the only difference as yet known being that the O is more stable, being more firmly connected with the molecules. Thus, the conclu- sion reached in regard to the interchange of O in the blood, is that only a small proportion of the O is absorbed on the basis of the law of partial pres- sure, the large proportion being in loose combination with the haemoglobin this combination being of such a nature that while O freely unites with the haemoglobin, it also becomes dissociated at a low pressure or by the action of indifferent gases, or under the influence of substances which have a stronger affinity for O than the haemoglobin. In the venous blood the haemoglobin is reduced while in arterial blood, the haemoglobin has a large proportion of O in combination with it, the purple color of reduced haemoglobin giving to the venous blood its dark hue, and the scarlet color

of oxyhaemoglobin to the arterial blood its bright scarlet color. The CO_2 in the blood depends upon other circumstances not so clearly understood. The CO_2 does not depend upon the law of pressure, and it is not simply dissolved in the blood; it is in association with some substances and can only be liberated by dissocation. It seems to be more largely in the blood plasma than in association with the red corpuscles. If blood serum be passed through the mercurial pump, a large proportion of CO_2 is given off. This is called the loose CO_2. If an acid is used, an additional quantity of CO_2 will be given off from the solution called fixed CO_2. If a volume of blood is passed through the mercurial pump all the CO_2 will be given off, indicating that all the CO_2 in the blood normally is in loose combination, loosely associated with some substance in the blood plasma, the substance itself being unknown.

In the case of O we find not only the haemoglobin in individual mole- cules, but collected in masses and bound up in the corpuscles. The haemo- globin is separated from the air in the alveoli by the plasma and the mem- brane of the capillary and alveolar walls, corpuscle being separated from corpuscle, and therefore the haemoglobin in each corpuscle is separated by a plasma layer through which the O must pass in order to reach the haemo- globin.

Each corpuscle occupies a certain area in the plasma, the pressure of the air in the alveoli and in the plasmic solution, and the amount of O in the hæmoglobin determing the interchange between the air and the blood. The plasma acts very much like the water solution in regard to the absorp- tion and elimination of O, the membrane of the capillary and alveoli wall be- ing kept moistened by the lymph so that the living membrane under the influence of moisture assists in the gaseous diffusion. Under the influence of a reduced pressure arterial blood ceases to take up O. This point in the reduction of pressure is represented as below the 300 mm barometric pres- sure mark, that is, when the reduction of O in the atmosphere amounts to more than one half, atmospheric pressure being 760 mm B. M. If the O of the air is gradually reduced after the O falls below 10 per cent of the atmos- phere dyspnoea follows; hence, it is said that at 17,000 feet above the normal level of the atmosphere, the atmospheric pressure is reduced to about 300 mm and the partial oxygen pressure is such that venous blood is unable to take up oxygen sufficient to convert it into arterial blood, resulting in con- siderable difficulty in breathing,

In the case of CO_2 it would seem that there is a diffusion from the blood in the minute capillaries surrounding the alveoli into the air in the alveoli. In order to this the pressure in the pulmonary artery must be always greater than the pressure in the pulmonary vein. The alveolar pressure of CO_2 is very difficult to estimate because the CO_2 comes from the blood into the alveoli. The experiments seem to indicate that the passage of the CO_2 from the blood into the alveoli takes place by diffusion. If a catheter sur- rounded by a small sac is injected into the bronchus of a dog so that by inflating the sac the bronchus can be occluded, in this way the entrance of fresh air can be stopped while a sample of the air in this portion of the lung can be taken out by the catheter and analyzed to discover the amount of CO_2. In this way it is found that the physical loss of diffusion explains the passage of CO_2 from the pulmonary capillaries into the pulmonary alveoli. In the mixing of air in the lung, the first force brought into play is the prin- ciple of diffusion depending upon the partial pressure at the different points on the respiratory system. The differences in the partial pressure depend upon the estimates we have already given. Knowing the composition of the mixed gases the partial pressure is easily estimated, each gas constituting an element of the combination exerting a partial pressure equivalent to its proportion of the combination. The first part of air expired contains a large proportion of inspired air and a small amount of air found in the respiratory passages preceding inspiration.

As the process of inspiration advances, more of the vitiated air comes from the lower respiratories, and less of the inspired air enters into the combination, the last of the expired air being almost wholly air from the lung alveoli. O is constantly being diffused from the upper respiratories to the smaller air passages and the alveoli, in other words from greater pressure to lesser pressure. Equilibrium cannot be established because freshly inspired air is constantly entering and after entering the lungs is constantly passing into the blood. The CO_2 is also constantly being diffused under the influence of pressure, the CO_2 passing from the blood to the alveoli, increasing the volume of CO_2 in the lungs and causing the passage from greater pressure to lesser pressure, the CO_2 being diffused from the lungs outwards. Secondly, the mixture of air in the lungs takes place under the influence of the tidal waves of inspiration and expiration, an air force pressure which causes partial diffusion of the gases. In the upper respiratories there is little difference between the gases in the air and the gases in the respiratories. At each respiration a fresh volume of air is introduced and about 3-5 of this volume is carried to the lungs while during expiration a similar volume of vitiated air passes from the lungs into the upper respiratories. In this way there is a tidal current that assists in promoting the diffusion of the gases. Thirdly, the cardiac pulsations exert a similar influence. At each heart beat there is set up a movement of the gases which tends to promote diffusion. This force plays a very important part in the continuation of respiration during suspended animation and in the case of the hybernating animals. Thus, it is impossible to account for the diffusion of the gases on the principles of diffusion alone. Physical and mechanical forces diffuse the O to the plasma where it comes into association with haemoglobin. On chemical principles the union of O and heamoglobin takes place at a low pressure. In addition to this the tissues of the lungs act as a secretory membrane, thus assisting in the process of diffusion. This is equally true of O and CO_2 although the evidence in favor of it so far is not entirely conclusive.

SECTION VIII—The Respiratory Changes in Connection with the Tissues

What takes place in the pulmonary capillaries in connection with the air cells also happens in connection with the systemic capillaries, the fluid transuding through the capillary walls and bathing the entire tissues, the O passing into this fluid and also, of course, collecting the CO_2 from the tissues and passing this into the blood. The only difference in connection with the tissues is that the comparative tension or pressure of the O and the CO_2 within the vessels and without the vessels in the tissues is found to be just the reverse of those found in conneetion with the lungs; the tension of the gases in the fluid being greater than the tension of the gases in the tissues. The tension of the O in the tissues is extremely low for this gas, that is the O, does not remain free in the tissues, but the O at once enters into combination with the tissue element and with some substance or substances found in connection with those tissues becoming a part of the tissue substance itself. Hence, the tension of the O in the blood is much greater

than the tension of the O in the tissues and this gas, therefore, freely escapes from the blood into the tissues. During the active contraction of the muscle, the protoplasmic substance passes through rapid decomposition changes, including the formation of CO_2. On the other hand, the tension of CO_2 in the tissues is greater than the tension of the CO_2 in the arterial blood. Consequently CO_2 passes from the tissues into the blood changing the blood from a bright scarlet to a venous color or a deep purple. The pressure of the CO_2 in the lymph is also less than the pressure of the CO_2 in the venous blood. It seems difficult to understand that this is so, how the venous blood can absorb the CO_2. The lymph, however, has modified its pressure by contact with arterial blood, both in the tissues and in the lymphatics. The pressure of the CO_2 in the tissues is estimated at 45 mm. and the pressure of the CO_2 in the venous blood is estimated at 41 mm. of mercury. The CO_2 that is thus set free is then absorbed by the blood loosely combining with the carbonates and phosphates found in the blood. The blood thus represents the medium of respiration containing within it the gases in solution. This has an important bearing upon breathing in connection with the tissues. It was first found that the tissues of the body as well as the fluids and the skin took up O and gave out the CO_2. Liebig was the first to point out that fresh muscle used up O and gave out CO_2 depending, to a large extent, upon the blood supply found in the muscles. This was followed by the observation of other Physiologists who found that the contraction of muscles used up a large amount of O and eliminated a larger amount of CO_2 than the muscles which are inactive. Muscle is thus found to possess a great absorption power for the O. In this way we find that the entire body takes part in respiration and not as was at first supposed simply the respiratory system. The O is breathed in, not only through the regular respiratory system, but also in connection with the skin; the CO_2 is eliminated in the same way. The O breathed into the body by respiration is breathed into the tissues. This respiration is subsidiary, and yet it has an important bearing upon the respiration of certain animals especially when these animals are placed in certain media. Respiration thus, presents many interesting features aside from the question of the simple introduction of air into the lungs. The question of the proportion of O absorbed to the CO_2 produced requires to be solved. In the case of the human subject the respiratory quotient is found as we have said, by dividing the variation of the CO_2 by the variation in the O, giving us a respiratory quotient of .87 varying to .75. This variation of the respiratory quotient in connection with the tissues depends upon the nature of the diet, depending largely upon the amount of carbohydrate substance found in the food. In the case of animals that are deprived of food, the respiratory quotient is represented as .75, indicating that the combustion takes place at the expense of the body substance in the case of a starving animal. The respiratory activity varies in the different animals, the general rule being that the smaller the animal, the higher the degree of its respiration. This, however, is only true to a limited extent. For example, a small singing canary requires 12 or 13 times as much O as a common fowl. In the case of a frog, it can live in an atmosphere containing one 150th part of the O necessary for the life of the canary. The fishes, like the frogs require only a very small quantity of O, the gases of the sea water being found in very small quantities. By a system of storage however, these animals—the fishes—can extract from the water the O and thus provide for themselves, a sufficient supply of O for a considerable period of time.

The importance of tissue respiration is evident from the fact that the chief chemical changes of the body take place in connection with those tissues. The same is true of the decomposition changes which result in the formation of the CO_2. The tissues have a strong affinity for O so that a very low pressure is sufficient for the absorption of a large proportion of the O. The tissues from this standpoint represent an aggregation of cells, each cell absorbing O and excreting CO_2. The cell activity depends upon the amount of O that is absorbed and the degree of oxidation in connection with the O absorption. Experiments have been made by Physiologists in connection with the different tissues of the body. For example, it is found that 100 grams at a temperatnre of 38°C, give the following results in connection with the different parts of the body. In ordinary muscles 23 C. C. in heart muscles 21 C. C., in the brain 12 C. C., in the liver and kidney 10 C. C., in the spleen 8 C. C. and in the lungs 7½ C. C. In the case of all these tissues, CO_2 is formed directly in proportion to the volume of O absorbed. The blood of the body as it circulates, carries the O to the tissues and it also discharges the function of disintegration and oxidation. 100 grams of blood for example, at 38°C absorb 8-10 of one cubic centimeter of O and produced the same volume of CO_2. In addition to this the blood bears partially oxidized substances from the tissues to the lungs. In the case of the muscles, when resting at normal temperature, the O absorbed is larger than the CO_2 eliminated, while, during the activity of muscles, more CO_2 is produced than the amount of O that is absorbed. This, however, is not fully tested as yet. The question now arises, "How do these processes take place and where does this process take place, in the blood, or does it take place in the tissues?" There are certain oxidizable substances in the blood and the blood has has a power of oxidation but when the blood is taken from the body this power of oxidation is found to be very small. We must take into account this fact, that this may be due to a certain extent to the fact of the removal of tne blood from the body. In the case of the muscle of the frog, for example, extirpated from the body no free O is found by subjecting the muscle to the mercurial air pump; while resting muscle produces O and also CO_2, even when no O can be obtained from the outside of the muscles. O is necessary for the maintenance of life and also for the maintenance of muscle irritability, although it is not necessary for the manifestation of that irritability. As we find, muscles will continue to exhibit irritability in an atmosphere charged with H or with N. Muscle, therefore, must have the power of absorbing O and also the power of storing O in its substance, so that the O thus stored can be used when required in the oxidation processes. At the same time there is a constant oxidation process going on in which case this stored up O supplies the necessary materials for the oxidation process. Muscles, like other body substances, are constantly passing through two changes, these being represented by the anabolic process and the katabolic process. During these processes the O is combined in some way with carbon. In what way this combination takes place in the muscular metabolism is not known, but that it does take place is well known.

As the presence of O in the muscles has nothing to do with the interchange, there must be a constant passage of O from the blood to the tissues, or from the red corpuscles through the plasma, the capillary walls of the lymph to the tissues. As the CO_2 is produced, CO_2 pressure or tension will force the CO_2 from the muscles through the lymph spaces, through the lymph, through the capillary walls into the blood plasma. Thus there is constantly going on, a double interchange between the blood and the tissues. In all the other body tissues, similar interchanges are found to take place, free O being absent from the tissues, the lymph and the plasma, whereas, CO_2 is present in abundance, in the tissues, in the lymph and in the blood plasma. Thus we conclude that when the O is carried to the tissues by the arterial blood, the pressure of the blood drives it into the tissues all the O thus passed into the tissues being stored away in some way in connection with the tissues, the combination being so stable that no free O exists in the tissues. In the same way by the continued activity of the muscles, CO_2 is produced, and this under the high pressure found in the tissues, is passed into the blood so that the venous blood with a high pressure of CO_2 passes out of the tissues into the venous circulation and finally into the lungs.

A subsidiary form of respiration is found to take place through the skin. In the case of the frog, for example, the skin, is the principal organ of respiration, death being produced from suffocation more rapidly in the case of the frog covering the skin over with an oily or greasy substance to prevent this cutaneous respiratiou than by compressing or ligaturing the trachae. By the extirpation of the frog's lung it is found that the amount of O absorbed, and the amount of CO_2 eliminated does not diminish at all or only to a very slight extent. In the human subject, on the other hand, the skin is only in a very subsidiary sense, an organ of respiration, the amount of air, as we said before, being about one 140th part of the entire volume of air absorbed in the form of O and excreted in the form of CO_2. The ratio representing the relation of lung absorption or elimination to skin absorption or elimination is placed as follows: In the case of O it is 1 to 100 or 200; in the case of CO_2 it is 1 to 250, giving normally about 1-150th, or a little more; in the case of cutaneous respiration the moisture of the skin freely assists the respiration and also the higher temperature of the external atmosphere.

SECTION IX.—Abnormal Respiration.

Pure air at the ordinary pressure and with the ordinary composition is necessary to normal respiration. In order to estimate the abnormal conditions of respiration it is necessary that we know the normal conditions and the normal quantities of gases used in respiration. The average quantity of O absorbed daily by an average adult is estimated about 700 grams varying up to 1100. Of the CO_2 it is estimated that in 24 hours an adult exhales from 700 to 1300 grams, the average being about 900. The amount of CO_2 however, exhaled depends upon the number of circumstances. 1st. It depends upon the number and the depth of the respirations. The amount of CO_2 is increased by increasing the number of respirations and also by increasing the depth of the respirations. Normal breathing expires 4.38 per cent at each expiration. In deep and slow expiration, on the other hand, this is increased to 5 per cent. 2d. The amount of the CO_2 depends upon the extent of the pause. In the case of a single expiration as the expiration advances the amount of CO_2 increases. If the pause is lessened more CO_2 is exhaled as the process of eliminating CO_2 from the blood goes on during the whole period of respiration including the pause. Thus, by lengthening the pause the amount of CO_2 accumulating in the lungs is increased, causing the expired air to be much richer in the CO_2. 3d. A number of minor causes also influence the amount of CO_2. For example, increased muscular activity increases the production of CO_2. An increase also in the body temperature increases the amout of CO_2 and vice versa.

The kind of food taken also affects the amount an increase, for example, in the carbon from the use of carbohydrates and vegetables increasing the production of CO_2. 4th. A number of circumstances tend to lessen the production of CO_2. During sleep, for example, CO_2 is lessened sometimes to a consideration extent. The deprivation of food has also a similar effect, the diminution reaching a minimum. The rapid lowering of atmospheric pressure produces in the lung capillaries an air bubble condition resulting in the diminution of CO_2 and very soon in fatal results. The body mechanism is designed to work under a normal pressure, varying from 760 mm. B. M. to about 500 mm. This represents an altitude of from sea level to 6000 or 7000 feet above the sea level. If there is any great change either of increase or decrease in the pressure it affects the entrance of O and the exit of the CO_2 and it also affects the process of the body, both chemical and physical. If an animal is placed in an air in which the pressure is greatly diminished as for example. in an air receiver out of which the air has been exausted, convulsions follow the gas freed from the blood inside the vessels, obstructing the circulation and also interfering with the cardiac movement. In fact any sudden lowering of pressure completely unbalances the entire vascular and respiratory systems. This unbalancing causes the feeling of distress that is associated with sudden change of pressure. This produces, in the case of the sudden lowering of pressure, the conditions which differ from asphyxia, namely muscular debility and paralysis due to the lack of nervous stimulation. In the case of the increase of atmospheric pressure where the increase is above a certain point the signs are a sleepy condition or an unconscious feeling similar to that which is produced in the case, for example, of narcotic poisoning due to the depression of the system. When the pressure rises to 15 atmospheres of air in this case we have 3 atmospheres of O, we will find convulsions and asphyxia taking place identical with the results found in connection with deficiency of O, the CO_2 production being decreased correspondingly and death resulting from asphyxia. Expired air always contains slightly more N than inspired air, the N being derived not only from the air that is inspired but also from the nitrogenous matters used as food, about 7 to 8 grams of N being eliminated from the system in 24 hours. In the case of H_2O it is estimated that about 300 grams are excreted from the lungs daily, this being taken from the blood and from the vapor in the air that has been inspired, the amount varying somewhat, according to the character of the air inspired, the depth of the respiration and also the duration of the respiratory period.

The respiratory mechanism can adapt itself to abnormal conditions within certain limits. Certain gases modify the respiratory actions and in some cases, suspend respiration altogether. Nitrogen or hydrogen may be breathed without any dangerous results i f a sufficient amount of O is present. Pure nitrogen and hydrogen when breathed quickly, prove fatal for lack of O. They may be inhaled without dangerous results if they contain 12 or 13 percent of O. Such gases as hydrocloric acid, sulphurous nitric acid and ammonia gas cannot be inspired because they result in spasmodic closure of the glottis, producing at the same time irritation of the respiratories. Other gases like carbonic acid, carbonic oxide, sulphurretted hydrogen, etc., enter into the lungs and produces dangerous results from interference with the normal respiration or have some poisonous effect on the blood of the tissues. Inspiration of pure CO_2 results fatally in a very short time but 25 to 30 per cent in the air does not prove fatal if not continued for more than a few minutes. Carbon monoxide is a very dangerous and

poisonous gas quickly destroying life when found to the extent of 1 per cent. It combines with haemogloblin so that the haemoglobin is prevented from performing its function in connecton with the carrying of oxygen. The blood under its influence turns into a very bright cherry color; .001 per cent of the air will affect the breathing and it is found that if 60 per cent of the haemoglcbin is combind with carbon monoxide the heart's action is effected, respiration is weakened and death gradually ensued. Nitrogen monoxide mixed with O is the ratio of 2 to 1 may be breathed so as to induce intoxication. This is called the laughing gas. If breathed in its purity it results in asphyxia. Sulphurretted hydrogen mixed with the air to the extent of .4 per cent causes the blood to become greenish and results fatally.

Certain expressions are used to denote peculiarities associated with respiration. When the respiration is normal and easy, the amount of O and CO_2 being normal it is called *eupnoea*. Variations from this normal are expressed as follows: *Apnoea* represents a state in which the respiratory movements are suspended. It may result from quickly repeated inspiration of air in which case the suspension takes place for a few minutes. In the case of artificial respiration, especially in animals subjected to trachcatomy, if the lungs are repeatedly filled artificially with air and then the inflation is stopped, apnoea follows. After a short rest the respirations begin very feebly, and gradually return to the normal. The cause was formerly supposed fo be found in the excessive amount of O in the blood and the lack of CO_2. If the blood becomes saturated with O the respiratory actions will be arrested. If bellows are used to inflate the lungs by diminishing the pause between the successive inflations, the respiration becomes slower and gradually is arrested altogether without arresting the cardiac movements. This is due undoubtedly to the large amount of O present, and the small amounts to CO_2. But this only represents one apnoeic condition. There is a connection between apnoea and the amount of O in the blood, the apnoea being more characteristic after breathing pure O than after breathing pure air, and the apnoea is less characteristic if O is not present in its full complement in the air. The arterial blood of apnoeic animals is hy peroxygenated. From this it is concluded that the blood is overcharged with O and that breathing is suspended till the O is exhausted or until CO_2 is produced sufficient to arouse respiratory activity. That there is something in this cause is apparent for the fact that by respiring pure O it becomes more marked than in respiring the pure air. To answer this it has been shown that by filling the lungs with pure hydrogen, apnoea may be produced, but not of such a marked character, the apnoeic pause being shorter, in some cases being entirely absent. This difference in the apnoeic pause has led to the conclusion that it is dne to the excessive storage of O in the air cells, thus rendering inspiration unnecessary.

The fact that hydrogen produces apnoea, although the hydrogen drives out the O from the lungs, indicates that the O does not furnish a full explanation. Apnoea, although hydrogen resulting from inflation of the lungs with air represents a condition in which enough O is found in the lungs to supply the blood. The fact that if the vagi nerves along which impulses pass from the lungs to the center be cut, hydrogen filling the lungs causes violent dyspnœa, whereas inflation of the lungs with air produces no result at all, seems to suggest that the repeated respirations stimulate the pulmonary peripheries of the vagus nerves, producing impulses which inhibit the respiratory center by depressing it and so preventing the respiratory center from acting.

Apnea may result from inflation of the lungs with air, pure O or pure H, the pause representitg the only difference between these, being shortest when pure H and longest when pure O is used. If the vagi nerves be cut and the lungs be inflated with H, no apnoea results. During the deglutition process respiration is arrested but this takes place by the inhibition of the centers, the inhibition originating in the terminals of the glosso-pharyngeal fibres. Apnoea may therefore be caused by mechanical action or by gaseous stimulation. In the latter case the apnoea is due to the excessive amount of O stored up in the lung alveoli; in the former case it is due to inhibition of the respiratory center, the inhibition being aroused in the vagus nerves and resulting in the arrest of the repiratory impulses. Both of these causes may be combined in the production of apnoea. If the act is voluntary, the breath may be held for a considerable time, especially if the act of holding the breath is preceded by a number of deep respirations. In this case the probability is that the nervous impulses are sent down from the higher psychic centers inhibiting the action of the respiratory center.

The will, however, cannot destroy the respiratory impulses because the will or the psychic influences from the psychic center cannot restrain those impulses which proceed from the respiratory center without destroying the respiratory activity. When the will is checked for a time the power of the respiratory center, the inhibition is then withdrawn, the respiration becomes normal. This inhibition may take place, either voluntarily or involuntarily indicating that the will has very little controle of respiration. This is shown from the fact that a number of deep respirations must necessarily precede even this brief stoppage of respiration. It cannot at once take place, that is, the will cannot suspend respiration without certain physical conditions being fullfilled, preparatory to the exercise of the will. This is sometimes spoken of as a brief conscious apnoea.

A pathological apnoea we have already described in connection with the Cheyne-Stokes breathing. The movements of respiration in this form of breathing gradually diminish in rapidity and also in extent until the respiration ceases during the apnoeic pause. These respiration representing a series representing successive respirations, diminishing both in extent and in intensity. This apnoeic pause in the Cheyne-Stokes breathing is alternative by dyspnoeic respirations, this dyspnoea respiration constituting the series of breathings or respirations. This form of breathing is explained by some Physiologists as due to malnutrition of the respiratory center, the variations in the respiration representing the decadence of respiratory activity. Other Physiologists, however, believe that this form of breathing is due to the inhibitory impulses. These inhibitory impulses arise from the higher centers or possibly are due to cardio-inhibitory action as this form of breathing is always associated with fatty degeneration of the heart. In *hyperpnoea* we find increased activity in the respiratory center. It is called thermopolypnoea. The increase of the respiratory activity is due to the direct stimulation of the respiratory center, either through a rise in the blood temperature or reflexly due to stimulation of some of the sensory fibers found in connection with the surface of the body, arising, for example, from an increase in the external temperature. When the body becomes abnormally heated by the presence, for example, of the body in a medium of hot air, the respiration becomes faster. This hyperpnoeic condition is peculiarly characteristic of heat dyspnoea, even when the blood becomes

hyperoxygenated. No apnoea results. This forms an additional proof of the fact that the apnoea is not produced by an excessive supply of O.

Dyspnoea is difficulty of breathing. It is generally found accompanied by slow and forced respirations. There are different forms, however, of dyspnoea. From some cause or other sufficient O does not enter into the blood or the blood becomes unduly venous on account of the excess of CO_2; hence, the respiratory center is strongly stimulated and violent inspirations, followed by violent expirations, take place. This dyspnoeic breathing is quicker and deeper, the venosity of the blood arousing the respiratory centers so that respiration becomes violent, resulting in the activity of all the muscles of respiration and almost all the muscles of the body.

There is a form of dyspnoea due to the existance of certain substances in the blood, these substances being derived from the muscles during active muscular operation. Dyspnoea may result either from a deficiency of O or from an excess of CO_2 or we may find both of these conditions combining together in the production of dyspnoea. In the case of the confinement of an animal in a limited space where the O supply is limited or when the air in such a limited space is saturated with H, in this case dyspnoea results, even when the CO_2 in the blood is less than normal. It may result also from breathing an air containing a large quantity of CO_2, even although more than the regular quantity of O is present and even, although, the blood contains less than the normal quantity of CO_2. For example, if a person is forced to breath an air containing 10 per cent of CO_2, dyspnoea results although there is sufficient O present both in the blood and in the air. If an animal breathes pure N the result is, that the respirations become frequent and the inspirotions are very strong. In the case of an animal breathing an air laden with CO_2 the respirations become slower and they are marked by strong expirations. This marked increase in the depth of respirations is due, not only to direct action upon the respiratory center but also and especially to the reflex actions upon the center conveyed through the sensory fibers of the large bronchi. Hence, the depth of respiration in connection with the inhalation of excessive CO_2 arises from the stimulation of the sensory fibers of the bronchial mucuous membrane. In the case of the inhalation of air deficient in O the exhalation of CO_2 is not affected at all.

It is marked, however, by increased blood pressure. This increased blood pressure continues for a considerable time before death takes place; death being preceded in this case by certain disturbances in the motor activity such as we do not find in the case of death, resultihg from the inhalation of air excessively charged with CO_2. The difference then, between the inhalation of air excessively laden with CO_2 and air deficient in O is explained in connection with the blood. The blood that is deficient in O influences the inspiratory center, whereas the blood that contains an excess of CO_2 affects the expiratory center. During the contraction of the muscles certain substances are formed, which pass into the blood, and consequently affect the respiratory center. Accompanying this muscular activity there is an increase in the respiratory activity, and in the case of strong muscular action dyspnoea, more or less marked results. These products of muscular activity, pass into the blood and the blood then acts as a stimulant upon the respiratory center. These substances are not known, although propably they are of an acid nature and are broken up in the blood, being carried through the system in the circulation. If the blood that flows to the brain is higher in temperature than the normal temperature of the blood, for example, if the blood of the caroted artery is heated artificially above the normal temperature, this will produce dyspnoea. In fact, anything that weakens the circulation, or diminishes the amount of haemoglobin found in the blood will cause dyspnoea,

If, for example the carotid and intervertebrate arteries are ligatured thus cutting off the blood supply to the medulla dyspnœa results, the blood in the medulla region being excessively charged with CO_2 and deficient in O. This accounts for the fact that people who are affected with heart trouble or suffering from anæmia become dyspnœic with the least over exertion. In the same way anything that tends to prevent the interchange of O and the excretion of CO_2 assists if it does not produce dyspnœa. Hence, pneumonic persons and those who are affected with lung tuberculosis are subject to dyspnœa on very slight exertion; Dyspnœa is characterized in general by an increase in the frequency and in the depth of the respiratory movements, hence, the ordinary muscles of respiration, the diaphragm and intercostals, especially tee external intercostals are assisted by the scaleni and by the serrati postici muscles. The ribs become elevated and depressed forcefully and the larnyx that normally is resting is forced up and forced down with considerable force; Hence, dyspnœa may be caused in the following ways: 1st of all, by a puncture opening into the pleural cavity thus obstructing the lung distension. 2d. By an excessive hemorrhage the blood loss in this case affecting the ordinary activity of the respiratory center. 3d. By diminishing the circulation of the blood, at least in the brain so that the brain does not receive a blood supply sufficient to keep the brain in active operation. This takes place, for example, if the valves of the heart are in a diseased condition or by an interference with the circulation of the blood in the carotid or in the juglar veins. 4th. Anything that prevents the normal passage of air to and from the lungs, as for example, in the case of partial strangulation. 5th. Congested conditions of the lungs. This condition lessens the respiratory surface, in that case preventing accumulation of O and thus interfering with the respiratory actlvity.

ASPHYXIA.—This literally means without pulse, but Physiologically it is applied to that state to ~~that state~~ in which there is a cessation of the respiratory rhythm due to the exhaustion of the respiratory center. Asphyxia generally results from the interruption of the process sf respiration, causea by the deprivation of air; for example, by placing an animal in a limited space so as to lead to the increase of CO_2 in the blood, cutting off the supply of O. Asphyxia may take place suddenly, as, for example, in the case of the complete blocking of the trachea, or it may take place gradually, as in the case where you have only the partial blocking of the trachia and other cases. In any case, whether the asphyxia is sudden or gradual, it is divided into three stages. 1. During the first stage we find difficulty of breathing, The respirations in this case are rapid, irregular and very soon become deep and labored, representing a condition of hyerpnœa. Asphyxia, we will find, is a combination, hyperpnœa and abnormal conditions that we find in connection with respiration. The muscles of respiration, especially the muscles of inspiration, are subjected in this stage to very strong contraction, and those muscles in the chest and in the abdomen, and those muscles in the chest and abdomen which are connected with inspiration contract very powerfully at intervals. After a brief space this intermittent contraction passes to the muscles of the lower part of the body, chiefly the flexor muscles. Through out the first period of asphyxia the O is exhausted, the blood becomes venous and the respiratory centers are subject to stimulation by the velocity of the blood, chiefly the inspiratory part of the center giving respirations of increaesd frequency and death.

2d Stage. The violent convulsions give place to deep and slow expiratory movements, the dyspnoea giving place, as we have said, to the convulsions. The inspiratory center ceases to be affected to any great extent and inspiratory movements become weak, whereas, the expiratory part of the respiratory center is strongly moved, resulting in very strong intermittent expirations, the respirations becoming slow and also deep. This 2d. stage like the 1st stage continues for about one minute. During both of these periods the blood becomes deficient in O resulting in the blue discoloration of the skin and also the blue discoloration of the lips and gums. The blood has become more venous, resulting in a strong stimulation of the cardio-inhibitory center causing the heart's action in contraction to be sensibly diminished. The respiratory centers in the medulla are excited and in the latter part of this second stage at least the spinal cord is also strongly excited, the vaso-constrictor center causing contraction in the capillaries and also producing a rise in the pressure of the blood.

3d. Stage: During this period general exhaustion follows, resulting in collapse. The inspiratory muscles at first act weakly and only intermittently, while the expiratory muscles give occasional spasmodic contractions, resulting in convulsions. In the same way the muscles of the extremities become spasmodically convulsive in their movements, chiefly the extensor muscles; gasping being associated with sharp, short respirations.

The pupils of the eye then become dilated, the lids of the eye do not close when the eye balls are touched, consciousness disappears and the reflex actions cease, The muscles, particularly the muscles of respiration, become soft and the convulsions give place to a quiet comatose condition. Afterwards the body becomes arched backwards especially the head and the body trunk. The lower extremities become stiff and stretched, the nostrils being expanded and the heart paralyzed. The right auricle and the right ventricle are dilated on account of the free flow of venous blood; while the cardiac muscular tissue become enfeebled, loose and flaccid. Finally the heart ceases to beat, the pulse cannot be felt and the respiratory centers become completely paralyzed. This period normally lasts 4 or 5 minutes. The heart, however, continues to beat very feebly for some time after the respiratory actions have ceased. If artifical respiration is induced before the cessation of the heart beat, the respiratory movements may be restored and the other functions revived. If asphyxial death results from the obstruction of the trachea, the three periods are somewhat shortened, the whole asphyxia period lasting about 5 minutes. If asphyxia comes on gradually, then the death takes place very slowly and it may result without any disturbance of the motor activity.

In the case of death by drowning, the complete submersion of the body for a very few minutes results fatally, death resulting either from suspended respiration or from the failure of the heart's action, It is more difficult to revive persons who have been submerged in water then to revive those who have become weakened simply on account of the lack of O. It is said by the Physiologists that resuscitation is impossible after complete submersion for five minutes. Newly born children are able to sustain life longer in the case of submersion than adults. After death, on examining the body, the blood is found to be very dark, particularly in the lung capillaries. In some cases the venous blood is almost black, the auricle and the ventricle on the right side of the heart, and the lungs together with the veins being gorged with blood, whereas, the arteries are almost, if not entirely empty of blood. This is due to the forcing of the blood into the venous circulation by the elasticity of the large arterial vessels.

During the 1st and 2d periods the pressure of the blood increases, the smaller vessels contracting, this contraction being due to the stimulation of the vaso-motor center in the medulla, increasing the strength of peripheral resistence. The heart's action becomes stronger for a short time, although the heart beats become less numerous under the influence of the cardio-inhibitory center, which has become excited. The heart beat at this point becomes more forcible. After this forcible beating of the heart for a short period, the heart action becomes feeble on account of the large quantity of the venous blood in the heart, the left ventricle being unable to force the blood out of the heart against the strong force of peripheral resistance. At this point the blood pressure falls to its lowest, marking the beginning of the 3d stage. This takes place on account of the paralysis of the vaso-motor center, due to the action of the venous blood. The venous blood, as we have said, gorges the right side of the heart when the blood flows from the small capillaries into the veins and then into the heart, injuring the cardiac muscle, and then enfeebling the action of the left ventricle, diminishing the peripheral resistance which results in a large fall in the arterial pressure and in the complete collapse of the system. These changes result mainly from the deficiency of O in the blood. With an increase in the velocity of the blood, the respiration becomes more frequent and greater in force, the expiratory action predominating over the inspiratory action, under the influence of the muscles that are brought into play, all the muscles of the body in this case being brought into active operation. These expiratory movements merge into the expiratory convulsions due to the excitation of the medullary center by the venous blood. If the spinal cord is divided below the medulla these convulsions do not appear. If the brain above the medulla is removed, these convulsion reactions still continue, indicating—what we will find later—that the respiratory center is in the medulla. This center is sometimes called the center of convulsion,or convulsive reactions. Although, the question of its independent existence is a matter of dispute. Some have indentified this convulsive center with the expiratory part of the respiratory center. If there is an independent convulsive center it must be in close relation with the main respiratory center because there is a close connection between the expiratory movements of respiration and the convulsive reaction. If the blood vessels supplying the brain are ligatured the same convulsions may be noticed, the centers of nervous activity in the medulla becoming asphyxiated through lack of blood containing the O. If there is a large loss of blood by hemorrhage, the same results may be noticed. These results are due to the stimulation arising from the deficiency of blood. During the last stage of the convulsions we find that these convulsions give place after the exhaustion of the nervous system to a calm and quiet condition, being interrupted at varying intervals by the inspiratory gasps. These inspiratory gasps mark the near approach of death. These inspiratory gasps also represent the gathering force of the inspiratory part of the respiratory center, until the center becomes entirely exhausted and all activity ceases in death.

SECTION X.—The Innervation of Respiration.

Pulmonary respiration we have said is carried on by means of the action of a number of muscles, some of which are in positions widely separated from each other, but all of which act together in a co-ordinate manner. If the intercostal muscles were to contract before the scaleni muscles, then the entrance of air and its elimination would be interfered with. Normal inspiratiom implies a quiet action of the various muscles and a forced respiration implies a

forced contraction of the muscles, otherwise the respiratory action would be impeded. All this co-ordination of action is accomplished by co-ordinating nerves. These movements are carried on involuntarily and autmoatically, the mechanism being so arranged as to possess self-controlling power. The muscles of respiration can be called into activity by the exercise of volition and the will can to a certain extent modify respiration. Yet the breathing is not normally voluntary. That this is proved by the continuance of normal breathing during uncousciousness and after the removal of the higher parts of the brain above the medulla in which the psychic centess are located. These muscular actions are all controlled by a nerve center situated in the posterior part of the floor of the fourth ventricle. If one phrenic nerve is divided the diaphragm upon that side ceases to move although respiration is not suspended. If the other phrenic is divided the whole diaphragm ceases to move and breathing in the thorax becomes very difficult. If one of the intercostal nerves is divided the intercostal muscles cease to act, corresponding with the nerve cut. If the spinal cord is cut below the origin of the roots of the phrenic nerves the respiration in the thorax ceases and the diaphragm still acts, the breathing being more rapid. If the cord, however, is divided just below the medulla all respiratory movement ceases in the thorax, the nasal portion and the glottis still continue to act. If the facial and the glosso-pharyngeal nerves be then divided these movements also cease Thus we have the proof of the co-ordination of action in the production of the respiratory movements, different parts of the nervous system under the direction of the center in the medulla co-ordinating the different parts of the respiratory mechanism. The complexity of the center is manifest for in ordinary inspiration we find a number of complex co-ordinating impulses followed by a number of complex co-ordinating impulses in expiration. Even when respiration becomes forced the co-ordination of the ordinary and forced respiration is complete. Even in dyspnoea and asphyxia the co-ordination is not lost until the whole body is thrown into convulsions. This does not take place however wholly in the centers for the co-ordination is completed in the passage from the centers along the efferent path through nerve cells and nerve fibers, the nerve cells playing a part that is analogous to the main center, co-ordinating the impulses that are to be sent out along the motor nerves. This is evident from the fact that in young animals after the medulla is removed respiration may be kept up artificially. This indicates that the entire nerve cell mechanism of the spinal cord plays an important part in the co-ordination of the impulses. In addition to this great center, other centers of lesser importance have been spoken of in connection with the spinal cord, these being called subordinate centers. In connection with the respiratory center there are also certain nerves that bear the impulses to and away from the centers.

INNERVATION OF RESPIRATION.

1. The respiratory centers (see the brain) except the medulla, may be removed and yet the respiratory movements will continue normally. If, however, the lower part of the brain is destroyed the rhythm cases. Respiration continues normally after the section of the spinal cord below the beginning of the phrenic nerve. Flourens by such experiments as these has concluded that the center of respiration is in the medulla, at the lower extremity of what is called the V in the medulla the calamus scriptorius in the gray matter on the floor of the 4th ventricle. He found that by destroying that part, respiration was entirely arrested and death resulted in a very short time. On account of this he located the respiratory center in a region, 5 mm. in diameter between

the nuclei of the vagus nerves and the spinal accessory nerves. The destruction of this portion of the brain was found to result fatally, and hence, it was called by Flourens a vital knot, noeud vital. Later researches have somewhat modified this conclusion of Flourens. It has been found, for example, that the area of the Flourens vital knot consists not of a center but rather of groups of nerve fibers arising from the roots of the vagi, the spinal accessory, the trigeminal and the glosso-pharyngeal nerves, these forming nerve paths rather than a center. It has been shown by some recent Physiologists that the removal of this vital knot does not of necessity prove fatal and later it has been found that respiration is not suspended, either by the section of the spinal cord below the medulla or by the division of the medulla just below the calamus scriptorius. The stimulation of the vital knot does not excite the respiratory activity but simply influences the characteristic tonicity of the diaphragm. Without locating or attempting to locate exactly the center of respiration, most recent Physiologists have concluded that there is a center of respiration, some were in the lower part of the medulla. This center consists of two parts, one part on each side of the median line, the two parts being closely connected together by means of commissures. These two parts of the respiratory center act simultaneously and yet their action is independent, having connections with the lungs and with the respiratory muscles on the two sides. If the median line is divided the two parts will continue to act simultaneously, whereas if the part on the one side of the median line is destroyed, suspension follows in the case of respiration on that side of the median line. If, on the other hand, after the division of the median line, one of the vagi is also divided, no impulses reach the center on that side from the lungs, producing the slowing of the action of the muscles of respiration and increasing the strength of the inspirations. If, on the other hand, the median line is left intact, stimulation of one of the vagi affects both sides and stimulation of the central end of one of the cut vagi tends to increase the activity of both sides. If the vagi are divided and the stimulation is applied to one of the vagi, high up in the neck, the respirations may cease altogether on that side if the stimulation is strong. From this it is concluded that the two parts on either side of the median line connected with the respiratory center act together as a single center while each part has the power of acting independently. Each central part is supposed to consist of two parts, the one on inspiratory center controling the inspiratory muscles, and the other an expiratory center controling the expiratory muscles. If stimulation is brought to bear on the inspiratory center the inspiratory muscles contract and if the excitation is strong enough the inspirations are spasmodically arrested. Marckwold by the use of electric stimulation in the case of the medulla proved that the expiration or the inspiration depended upon the intensity of the stimulation, the period of the respiratory circle during which the stimulation was applied and the position in which he placed the electrodes. The motions were produced by excitation of the different or the sensory fibers indicating that they were reflex in their action so that by electrical stimulation a purely artifical respiration can be produced. Under this electrical stimulation he found that the expiratory center was more difficult to call into activity than the inspiratory center. This connection is of such a nature as to give to the center of inspiration an accelerator action and to the expiratory center an inhibitory action. In the case of the stimulation of both inspiratory and expiratory centers the accelerator action overbears the inhibitory action, giving to the whole respiratory center a prevailing accelerator activity because the accelerator activity because the accelerator element seems to be more powerful and more easily excited.

Rosenthal has proved that if the medulla is cut off from all afferent connection by cutting it below the corpora quadrigemina and also by driving the posterior roots of the spinal nerves and the pneumogastric respiratory activity still continues. These respiratory actions however take the form of spasms, indicating that the respiratory center in the medulla can produce automatically spasmodic activity. The efferent impulses, therefore influence reflexly the normal respiration.

Some writers claim that there is a respiratory center, or centers in the spinal cord acting automatically and also by reflex action from the peripheral. Other Physiologists have claimed that higher centers exist in the upper part of the brain. One has been located, for example, in the prominence of the grey matter of the brain between the optic tracts and the corpora albicantia, the tuber cinereum associated with violent respirations upon stimulation. This has been called a polypnoeic center. Upon the stimulation of this center respiration becomes very rapid. If a rabbit, for example, is placed in a high external atmosphere, respiration becomes very quick. If this part of the brain the tuber cinerium is extirpated these increased respiration are either arrested altogether, or the respirations become much slower. Another center has been located by some Physiologists in two anterior bodies of the corpora quadrigemina, associated with expiration and inhibitory action. An inspiratory center is also claimed in the posterior bodies of the corpora quadrigemina. This portion acting as an inspiratory and accelerator center. Another center is located in the upper part of the pons Varolii, acting as an inspiratory accelerator center. Other physiologists claim that in the lateral wall of the 3d ventricle there, is a center which deepens inspiration by stimulation and on the floor of the 3d ventricle there is said to be an area connected with the optic and the auditory nerves, under stimulation accelerating the respiratory rate, and if excited by strong stimulation, particularly mechanical stimulation, arresting the inspiration altogether. There can be, however, no satisfactory reason to establish any of these as true centers. Even if these are centers it is possible that they are entirely subordinate to the main center in the medulla, these stimulations passing downward to the true center.

In order to establish any of these as independent centers it would have to be proved that the injury or removal of these centers would result in stopping or modifying respiration and also that there are nerves connected with the respiratory organs and muscles leading to these centers. Some have regarded the spinal centers as the principle centers. This however is impossible. Respiratory centers have been supposed to be located in the spinal cord chiefly for the reason that after dividing the spinal cord from the brain, where it joins the medulla, respiratory movements continue at least for some time. In the case of new born animals respiration will continue some time under these circumstances. If animals have been artificially subjected to respiration and after cessation of artificial respiration the spinal cord is cut below the medulla respiration continues. From this it has been concluded that a respiratory center must exist in the cord acting both automatically and reflexly. There is probably a chief center in the medulla and subordinary centers in the cord, in special cases these centers acting alone when the great center is inactive from some cause. But the respirations in such cases are irregular and rather spasms than respirations of a normal character. It has been observed that if the medulla be removed from the influence of all afferent nerves by cutting it under the corpora quadrigemina and also dividing the vagi and the posterior roots of the spinal nerves, respiration continues but the respirations assume a spasmodic form of inspirations and expirations. Thus by automatic activity the medulla can produce spasmodic actions. Normally, however, it is subject to afferent impressions so that normal respiration depends upon reflex action. The rythmic action of the center of respiration is communicated by means of impulses to the respiratory movements, the center discharging those impulses. This power of producing the rythm is inherent in the center, if not entirely, to a large extent, not being caused by external stimulation so that the center is automatic to external stimuli. It is not so in relation to the blood, for when the center is in isolation from afferent impulses, the activity is continued on account of the stimulation of the blood, the automatic discharge of impulses depending upon the blood.

The rythm must be inherent in the center, for it is not destroyed by dividing the vagi and the glossopharyngeal, and the spinal cord either below the medulla or in the lower cervical area. The activity of the center and its rythm may be modified by influences reaching it from the higher centers; for example the effects of the various mental states and emotions upon respiratory movements is well known. It may also be influenced by the will for the respiratory rhythm may be voluntarily altered both in character and rate. The respiratory center is thus not a voluntary center, although it may be influenced by the activity of the higher, voluntary centers. As the action of the respiratory center still continues when the afferent nerves leading to it are divided, the center cannot properly be a reflex one. It must, therefore, be an automatic center. Yet through the activity of the center does not depend upon reflex stimulation, its action may be and continually is influenced by impressions reaching it along afferent nerve paths. If one vagus nerve is cut the respiratory movements become slower; if both are cut respiration becomes slower and deeper, the pause in each respiration being marked by prolonged. The stimulation of the cut end of the central portion of the vagus nerve lower than the laryngeal branches restores the normal rapidity and character of the respiratory rhythm, and if the stimulus is sufficiently strong causes the diaphragm and other muscles of inspiration to pass into a state of tetanus so that respiration is suspended in a state of deep respiration. From this fact, that section of the vagi diminishes respiration and that stimulation of the cut end causes an increase, it is evident that under ordinary circumstances influences are continuously ascending the vagi to the center from the lungs and quickening the action of this automatic respiratory center. By the stimulation of the sensory nerves of the skin heat tends to increase, and cold to inhibit the respiratory activity.

The rhythm of respiration includes the rhythm of both inspiration and of expiration. Normally, in inspiration we find muscular action, whereas in expiration, as we said before, there is very little of the muscular element that enters except in the case of forced or labored expiration. In the labored expiration the muscular element is really the prevailing element. Thus, there is an alternation between inspiration and expiration more marked when either inspiration or expiration becomes deep. Some Physiologists think that in the nerves there are to be found fibers connected both with inspiration add expiration, thus controling the inspiratory and the expiratory centers and alternating in the carrying of impulses to the centers. Inspiration and expiration takes place alternately, however, without such a connection on the part ot the vagus nerves. This is evident from the fact that by the section of the vagus and the consequent separation of the center or centers from the action of the vagus nerves, alternation of these respiratory movements still continues. The rhythm of the inspiratory movements is dependent, therefore, upon the respiratory center aside from its connection with the afferent nerves. The activity of the

respiratory center is manifested in certain chemical changes that take place in the nerve cells contituting the center and this activity of the nerve cells is sustained by its relation to the blood flow and the rate as well as the character of the respiratory movements, depending upon, not a single influence but a complexity of influences which may and do continuously affect the center; for example, the will and the emotions and the condition of the blood supply, particularly the blood supply to the brain. If both the vagus nerves are divided we find that respiration continues but only in a modified form. If the spinal cord is cut below the medulla the respiratory movements still continue, at least in the face and in the larynx, indicating that the activity of the respiratory center continues. even, although the vagus influences are entirely cut off and even when the movements of the thorax cannot be normally executed. The cranial nerves, except the vagus, are not especially brought, therefore into play in respiration, aside from the fact that they constitute a path for the conveyance of nerve impulses. If these cranial nerves are cut, leaving the cord undivided, the respirations still continue almost normally. This indicates that respiration discharges from the center do not depend solely upon the afferent impulses that reach the center along the afferent paths. Some of the impulses therefore originate in the center itself and the center, therefore, possesses the power of originating impulses, although these impulses are considerably modified by the afferent impulses. This indicates that the center of respiration is automatic in its action. Respiration is a double action so that nerve impulses may afiect either part of the center or both parts of the center. In this way affecting either part of the respiratory movement or both parts of the respiratory movements. Nerve impulses may diminish or increase the depth of the volume of respiration. They may also increase or diminish, the respiration rhythm, and this seems to be their sole function. Thus, the respiratory center is subject to the following influences:

1st. The influences of the higher centers. 2d. The influence of the afferent nerves, and 3d. The influences of the blood.

1ST. THE INFLUENCES OF THE HIGHER CENTERS.

All Physiologists admit that there is an influence exerted upon the respiratory center by the higher centers. For example, the strong excitation of any of the nerves of the special senses influence respiration. The optic and the auditory nerves on stimulation results in inspiration impulses and the stimulation of the olfactory nerves in expiration impulses. Similarly, the powerful excitation of the sensory fibers of the 5th cranial nerves as in the case of sneezing, results in expiratory movements. All the sensory nerves of the head act in a similar way conveying impulses to the brain producing inspiratory and expiratory impulses which are sent down to the respiratory center in the medulla. If the medulla is divided high up on the floor of the 4th ventricle so as to divide it from the brain respiration will cease for a few minutes and then may resume again, the breathing going on almost normally as before, the only difference being in the extent of the movement of inspiration, the variation being almost the same as we find in the case of sleep. If a transverse division is made lower down the respiration become forced, and if the incision takes place at the point of the calamus scriptorius, the respirations become periodic with long pauses, the respirations gradually diminishing in force and in number. In this condition by the stimulation of the sensory cutaneous nerves this periodicity will be removed and the normal respiration will be restored. The simple pressure upon the medulla cannot produce this periodicity of respiration.

There must be an inhibition of some of the normal stimuli that come down to the respiratory center in order to interfere with periodicity.

This throws some light upon the abnormal condition of respiration that we find in certain diseased conditions of the heart and of the lungs in which, as we said before, breathing becomes perodic with long pauses, lasting about 8-10 of a minute succeeded by superficial respirations which become deeper and deeper until the series of 20 or 30 respirations, is completed, after which a new series begins of the same character, each series becoming deeper in the first part, and lighter in the second part, as the series goes on. In this case the pause may be shortened by arousing the interest of the patient, in other words, by exciting the higher centers, and also by the section of the vagi. In the last case section of the vagi causes these periodic breathings to give place to spasmodic breathing, hence, perodic respirations arise when the higher nervous centers are in a condition of lethargy, either inactive on account of inability to perform their function, or failing on account of inhibition of some kind to send down impressions from the higher part of the brain to the lower centers along which we find the respiratory center. Thus the Cheyne-Stokes breathing occurs when higher centers send down no impulses to the respiratory center. This indicates an important point in connection with the innervation of respiration, namely, that the normal condition of the respiratory centers depends upon two things. 1st of all, upon the active normal condition of the higher centers of the brain, and 2d, upon the activity and operation of the vagus nerves through which the afferent impulses are brought to the respiratory center.

2D. THE INFLUENCE OF THE AFFERENT NERVES.

These afferent nerves are the vagi, the glosso-pharyngeal, the trigeminal and the cutaneous nerves. Impulses passing along the pneumogastric have an important influence on the respiratory center because this, as we said, bears the afferent impulses to the respiratory center. Hence the action of the vagi is the most important in connection with respiration. These influences of the vagi nerves can best be brought out in connection with the section of these nerves and the effects that are produced by stimulation of various kinds applied to these nerves when divided. When the medulla has been separated from the higher centers, if the vagi are divided there results a lengthened spasm of inspiration followed by spasmodic inspiration and expiration, resulting in a short time in death.

If the vagi, on the other hand, are cut off before the separation of the medulla from the higher centers the respiration will continue for a time normally and after a few moments the respiration will become deeper and slower followed in a few moments more by respiratory spasms. The absence of impulses passing through the vagi can be made up for by certain impulses arising in the brain and passing from the higher portion of the brain to the respiratory center. If the impulses are suspended only from the one side the rhythm is not affected, but if the impulses from both sides are suspended the centers act without any rhythm at all. This indicates that the rhythm of respiration depends upon the afferent impulses that are borne to the respiratory center by the vagi nerves. The vagi and the upper parts of the brain are therefore the media through which pass the impulses that influence the respiratory rhythm and the respiratory action. In the case of the vagi these impulses are constant; whereas, in the case of the upper parts of the brain the impulses are only occasional and intermittent. It is through this latter channel that the volitional and the emotional and the mental impulses pass to the respiratory center as well as those impulses that come from the special organs of sense. The lungs send their impulses along the vagi, these impulses affecting the center in causing the discharge of energy. The excitation of the vagus nerve in the neck produces strong inspirations and if this excitation becomes strong the inspiratory muscles may be thrown into a tetanic condition. In some cases the strong stimulation of the vagus nerves produces expiratory activity according to the period of the respiratory rhythm at which the stimulation is applied. Hence we conclude that the vagus contains both the inspiratory and the expiratory fibers. The impulses borne along the vagus so stimulating the respiratory center that there is rhythmic liberation of energy taking place which results in inspiratory and expiratory movements.

Marckwald says the respiratory center is automatically active but if the vagus influence is cut off then only spasmodic action results in the case of respiratory activity. The vagus is thus in constant operation conveying those impressions from the lungs to the center producing this discharge of energy which prevents the centers from becoming over-stocked. The center in the medulla is thus influenced from below by the vagi nerves and from above by the upper centers. The division of one vagus may have no affect at all or it may have only a slight effect upon respiratihn. The respiratory activity diminished grrdually, thus resulting in the production of slower respiratory movements and also in longer and deeper inspirations and shorter expirations. The effects quickly pass away. If both the vagi, however, are divided, the respiratory rhythm is diminished sometimes at once and at other times later.

This is followed by slow and deep inspirations. The inspirations then become gradually more forcible, accompanied by strong expirations, and a pause between each inspiration and expiration representing the abnormal pause. If the divided ends of the vagi are left unstimulated, the respirations become irregular, the inspirations becoming weak, the expirations are intermittent and between the inspirations and the expirations there are long pauses. These varying results in connection with the division of the vagi nerves are explained by the fact that the inspiratory fibers are less sensitive to weak stimulation than the expiratory fibers, and that there is mechanical stimulation when the fibers are divided. This mechanical stimulation arouses the expiratory activity. If the central ends of the divided nerves are irritated the inspiratory and the expiratory impulses become more powerful. If the one vagus nerve be divided and the central end of the cut nerve be stimulated, different results will follow these results depending upon the character of the stimulation and also the strength of the stimulation. For example, electric stimulation affects both inspiration and expiration. Mechanical stimulation affects only inspiration. Chemical stimulation affects only the expiration. If the electric current is weak, inspiration is lessened and expiration is lengthened. If the electric current is increased in strength the expirations become more frequent and the inspirations become deeper and stronger, the stronger current arousing the inspiratory fibers and accelerating the inspirations. If the vagus nerves become exhausted by excessive stimulation, then the application of the stimulation to the central end of the cut nerve results in increased expiration, the inspirations, on the other hand, being very short and weak, where as the expirations are long and deep, a pause occurring between the two. If the irritation is made very strong then the respiration is arrested in expiration. These opposite results are due to the two kinds of fibers, the two kinds of fibers being different in function, the one accelleratory and the other inhibitory. Each fiber has its own function, the one bearing impulses affecting the expiratory part and the other impulses which affect the inspiratory part of the center.

The different fibers are differently affected under the different degrees of stimulation. Both kinds of fibers carry impressions originating in the vagi peripheries in the lungs. The inspiratory fibers respond more readily to weak stimulation, and they are not so easily exhausted. If the stimulation, on the other hand, is medium or strong, the inspiratory fibers are more easily affected so that the inspiration action prevails. The expiratory impulses, however, may arise in the laryngeal nerves, especially in the superior laryngeal.

The superior laryngeal nerves are sensory branches of the vagi passing to the larynx. The excitation of these produces expirations and as the nerve fibers are very sensitive strong stimulation produces a stoppage of the respiration with a tetanic condition of the muscles of expiration. For example, the presence of irritant substances in the larynx immediately stops inspiration. When the stimulation is weak respiration becomes slow and the pause is lengthened. If the stimulation is strong the arrest of respiration takes place in expiration. These nerves seem to be expiratory nerves acting as such, even when the medulla is divided from the upper part of the brain. They do not act constantly like the vagi but simply act temporarily when some irritation affects the larynx, impulses being originated that stop inspiration. The impulses which arise in the lungs originate from the mechanical stimulation of the lungs. Some Physiologists think that the stimulation arises from the gases that are contained in the air vesicles. According to this, during expiration the increased CO_2 contained in the vesicles stimulates the inspiratory fibers, terminating in the lungs, the impulses being carried to the inspiratory center. On the other hand, the dilatation of the lungs during the act of inspiration stimulated the expiratory fibers terminating in the lungs arousing impulses carried to the expiratory center. The mechanical lung movements, however, are stronger and originate the impulses which affect both inspiration and expiration. In the case of the glosso-pharyngeal nerves their division does not affect respiratory movements whether the vagi are divided or not. Their stimulation is followed by an arrest of respiration for a period equal to three preceeding respirations. After that breathing commences with inspiration just from the point where the diaphragm was arrested. The glosso-pharyngeal nerve, therefore, is a nerve of inhibition coming into active operation at the commencement of deglutition. During the process of deglutition respiration is stopped, there is first a stimulation and afterwards an inhibition the stimulation taking place through the sensory nerves of the tongue and the pharynx and the inhibition through the glosso-pharyngeal nerves. The inhibition of respiration makes it possible to swallow either food or drink without drawing them into the larynx. The stimulation that passes through the sensory nerves to the center excite the mylo-hyoid muscles used in swallowing and then the inhibition takes place so arresting the breathing as to prevent the food from passing into the lungs. Thus, during the deglutition process the breathing is temporarily arrested. Nervous impulses seem to pass by irradiation from the deglutition center to the respiratory center, causing a short inspiration followed by inhibition through the glosso-pharyngeal during a longer period. As soon as the food is swallowed the inhibition ceases and respiration is restored. The trigeminal nerves of the nose may be excited so as to cause the arrest of respiration in the case of certain irritants, for example, certain poisons, gases, fumes, etc.

Tobacco smoke introduced into the nostrils or into the lungs of a rabbit causes the stoppage of the respiration. In the same way ammonia breathed through the nose or introduced into the lungs results in tne arrest

of breathing in expiration. Odors may in the same way affect respiration through the olfactory nerves. Respiration is also influenced through the center by impulses conveyed along the cutaneous nerves. Slight stimulation of a sensory nerve has not any decided effect but if the exitation is strong there is first an increase in respiratory movements followed by a number of deep inspirations and the cessation of expiration, for example, the sprinkling of the body or the face with cold water, plunging into a cold bath excite inspirations by stimulating the sensory cutaneous nerves. These are reflex impulses and they are more decidedly marked if the higher centers have been severed from the medulla, becoming distinctly spasms, passing into the convulsions if the stimulation is very strong. If the splanchnics are stimulated strong expirations result and may result in an arrest in expiration. These actions, however, are only temporary and affect respiration occasionally.

3d. THE INFLUENCE OF THE BLOOD.

The respiratory center is also affected by the condition of the blood through the influence which the blood exerts on the peripheral extremities of the vagus nerves distributed to the lungs. The activity of the center is directly affected by the state of the blood. Various theories have been propounded historically as to the nature and the cause of this influence. It was first suggested by all that excess of CO_2 in the venous blood brought to the lungs stimulated the pulmonary branches of the vagi producing inspiration.

Later it was supposed that the same cause of stimulation applied to the sensory nerves. Rosenthal then suggested that inspiration resulted from the deficiency of O in the medulla, his idea being that the respiratory center depended for its stimulation to activity, upon the oxygenated blood, passing through it. The vagi impulses went up according to this view to the center, lessening the pressure existing in the center, the superior laryngeals increasing the pressure and thus respectively assisting inspiration and expiration. These theories have all been based on the idea that the stimulating cause of respiratory movements is found in the gases of the blood in its circulation through the brain, both deficient oxygenation and excessive carbonization exciting the center. The former produces inspirations and the latter expirations. In opposition to this theory we find Hering defending the idea that the mechanical expansion of the lungs during inspiration, arouses the vagi nerves which convey impulses to the center, giving rise to expiration. On the other hand, the reaction of the lungs resulting in contraction, stimulates other nerves, arousing the center to inspiratory action. This theory is negatived by the fact that respiration may continue after the removal of the lungs. The theory of Rosenthal based upon the deficiency of O as the cause of inspiration, is disproved by the fact that the blood of apnoeic animals is deficient in O. The most reasonable theory, therefore, is that defended by Marckwald, who says that the normal stimulation of the center of respiration is not due to deficient oxygenation of the blood or its excessive carbonization, as certain animals, such as the hybernating marmot have been deprived of the circulation altogether without interfering in any way with respiration. Respiration continues after a severe hemorrhage, the center continuing active, depending for its nourishment upon the fluid found in the substance itself, or lying between the different centers. When the anabolic process advances to a certain point the substance itself yields to dissolution during the anabolic process, thereby setting free eneygy that produces spasmodic respiration. After this, a still further process of anabolism follows, resulting in the same change and so on successively.

During katabolism the branches of the vagi terminating in the lungs are active, producing by impulses sent to the center a diseharge which maintains the respiratory rhythm and prevents spasmodic activity. If the anabolic process is stopped apnœa results, so that the vagi are the direct producers of the katabolic changes which result in respiratory action and rhythm. If the blood is more highly arterialized than it is normally from any cause, for exampla, by breathing an atmosphere too rich in O, the respirations are slowed and may even be suspended, the person passes rapidly into an apnœcic state. If, on the other hand, the blood is more venous in character than normal, for example, from the air not being allowed to enter the lungs, from breathing an atmosphere containing to much CO_2 or from such excessive tissue respiration as occurs in great muscular exertion, the respiratory movements become more rapid and also more violent. In addition to this, various other muscular movements, such as convulsions will occur, due to stimuli being sent from the respiratory center to various other motor centers. This state of dyspnœa continues until the energy of the respiratory center is exhausted unless fresh O is introduced into the blood. After this exhaustion the respiratory movements gradually cease and a state of asphyxia follows. From this it is evident that the increase of O with the diminution of CO_2 in the blood lessens while the opposite condition increases the activity of the respiratory center. A rise or fall in the temperature of the blood produces similar changes in respiration. Each successive breath is not determined by the blood condition in the brain at the time of breathing. The center of respiration is automatic, at least to external stimulation. The rhythm of respiration depends upon certain molecular changes taking place during the metabolism of the substance. Any impulses that affect the center have an influence upon this metabolism. The lack of O and the excess of CO_2 affect in some way the complex processes of katabolism and anabolism. In the case of difficient oxygenation rendering the structure of the center more unstable and in the case of excessive carbonization increasing its explosive character.

The same is true of excessive muscular activity sending up to the medulla a blood so changed in character as to affect the center, the blood leaving the muscles in case of great muscular activity, being more venous than normally. This venosity of the blood does not account for the change in the center, for the blood that leaves the left side of the heart in cases of great muscular activity is not less oxygenated, but more oxygenated than usual. This has led to the suggestion that it is due to the presence in the blood of an acid, like sarcolactic acid. Whatever the substance may be the respiratory center is affected through the blood. Thus, the respiratory center may be influenced by impressions sent along the afferent nerves by some disturbance in the gaseous interchange in the lungs or by so changing the character of the blood that circulates through the brain as to modify its metabolism. All of these influences affect the breathing and assist in the adaption of the respiratory mechanism to the bodily organism. Deficiency in respiratory aeration may be found in deficiency of O or excess of $C\,O_2$. If an animal breathes an air containing N, $C\,O_2$ is eliminated normally, and the blood has its normal amount of $C\,O_2$, yet the animal becomes dyspnoeic and asphyxiated, if the N is breathed for a time. This is due to the want of O. If the animal breathes an air laden with $C\,O_2$ with a sufficient amount of O present no asphyxia follows, although the blood is excessively laden with $C\,O_2$ the respirations become deeper and more rapid, inducing unconsciousness, indicating that excess of $C\,O_2$ affects the higher part of the brain. Thus the center of respiration receives it impulses from several sources. 1st, the higher parts of the brain. If these upper parts of the brain are inactive while the pneumogastrics are not divided, and in activity we have the abnormal respiration called Cheyne-Stokes breathing. 2d, the pneumogastrics are the constant bearers of impulses in connection with normal respiration in contrast with the upper parts of the brain which do not constantly influence respiration. These two represent the great nervous influences in connection with respiratory actions. 3d. The reflex activity of the sensory and cutaneous nerves may arouse respiratory action, although these cannot take the place of the constant action of the pneumogastric and the higher parts of the brain. 4th. Occasionally the influence of the 5th cranial nerve, the superior laryngeal and the glosso-pharyngeal nerves exert an inhibitory influence in slowing respiration and sometimes arresting it in expiration.

4TH. EFFERENT INFLUENCES FROM THE CENTERS.

From the center there are transmitted at regular intervals through the various nerve fibers nervous impulses which stimulate the different muscles of respiration. These impulses are all sent, or supposed to be sent through subsidiary centers situated in the spinal cord, before they actually reach the particvlar nerves which supply the respiratory muscles; and tnese subsidiary centers, may in exceptional cases, carry on the stimulation of the inspiratory muscles when the chief center, for some reason, has been disabled.

During respiration, the only efferent nerves along which the nervous impulses that produce contraction of the muscles pass are the phrenic nerves to the diaphragm, the intercostal nerves to the intercostal muscles and the facial nerves to the dilatores nasi. The division of one phrenic nerve results in the paralysis of that side of the diaphragm. The division of both phrenic nerves results in the paralysis of the entire diaphragm. In this case inspiration is hindered because it depends entirely upon the other muscles while the diaphragm is so relaxed as to be pulled inside the chest at each inspiration. In this way the diaphragm retards rather than assists as it normally does the respiratory activity, death results in a very short period from asphyxia. If the spinal cord is divided beneath the junction of the 5th cervical nerve the costal respiratory movements are suspended entirely. In this case the phrenic nerves remain intact, and hence, diaphragmatic action would continue almost uninterrupted. If a division is made of the spinal cord just above the origin of the phrenic nerves, both the costal and the diaphragmatic impulses are arrested although the respiration still goes on almost normally in the larynx. During normal respiration impulses are carried to the larynx, causing the glottis to open during inspiration.

These impulses pass along the laryngeal branches of the pneumogastrics. If the pneumogastrics are divided above the origin of these laryngeal nerves, respiration will cease in the larynx, the laryngeal muscles being paralized and the glottis being closed. The nerves of the lungs are the vagi, the sympathethetics and the upper dorsal nerves. The pneumogastric sends out branches into the lungs, these branches affecting the respiratory activity. Not only do we find general impulses passing through the vagi but there are special fibers fn connection with respiration. It has been found, for example, that by excitation of one pneumogastric the bronchi of the lungs become constricted. On the section of one pneumogastric the bronchi on that side are dilated. The stimulation of the peripheral and also of the central ends of the divided nerves produces a contraction of the bronchi on both sides. The contraction, however, is less marked when the central end is stimulated. In the case of the administration of ether or chloral, this stimulation of the cut peripheral or central end of the vagus produces dilatation of the bronchi. This seems to indicate, first of all, the existence of constrictor and dilator bronchi fibers in connection with the pneumogastric. 2d. That both of these fibers, constrictor and dilator fibers, pass through the pneumogastric representing the afferent constrictor and dilator fibers, these being found by the stimulation of the peripheral end of the pneumogastric affectin both lungs so that each pneumogastric sends both constrictors and dilators to both lungs. When sensory nerves are stlmulated, there is in fact only a slight effect by way of contraction. Various experiments have shown the existence of pressor fibers, the excitation of which produces a contraction of the air vessels of the lungs. The afferent pressor fibers are found in the vagi while the efferent pressor fibers pass through the sympathetics to the lungs. 4th. There are trophic fibers in connection with the vagus and also with the sympathetics. By dividing one vagus for example, there are found to be certain changes taking place in the lungs. For example, the inflamation that is present in the lungs due to the severence of the trophic fibers is accounted for by the fact that nutrition is cut off from the lung substance. 5th. There are also sensory fibers in the vagus reaching the trachea, the larynx and the lungs. This is proved by the fact that a section of these fibers destroys sensibility. 6th. In addition to these the sympathetic nerves furnish vasomotor fibers, these vasomotor fibers arising from the spinal cord in the anterior roots of the 2d, 3d, 4th, 5th and 6tn dorsal nerves, passing to the sympathetic and from the sympathetics to the first thoracic ganglion and thence to the lungs. These represent the chief nerves that we call the efferent fibers that reach the lungs.

THE RESPIRATORY CENTER IN THE FŒTAL LIFE.

In the fœtal life the fœtus receives O from and gives CO_2 out into the maternal blood. The respiratory center is in a condition of apnœa resulting from the large quantity of O in the blood and also from the absence of irritability. In the fœtal blood there is a large percentage of hæmoglobin and also a large capacity for respiration. Normally however the child does not breathe in the uterus. In abnormal conditions, however, where the O supply is intenfered with there map be respiratory movements even when the child remains intact in the fœtal sac. If the blood should become very venous this excitement would produce respiratory action. This respiratory action, however, would be abnormal. So long, therefore, as a child remains within the embryonic membrane, respiration normally is impossible even if the activity of the center of respiration is aroused, because if such respiratory movements look place then the nasal cavity would be filled with fluid. This fluid acts as an irritant upon different nerves, setting up impulses which inhibit the center of respiration so that in the fœtal life the respiratory system is intact and complete but there is a constant inhibition by the action of the fibers of the nasal cavity. This forms the reason why sometimes after birth, it is necessary to remove the mucous from the nasal cavity in order to produce respiration. The mucous so long as it remains in

the nasal cavity produces the inhibition of the respiration activity. The fœtal lungs have no air although they occupy the entire space of the chest cavity along with the other organs. When inspiration commences in a newborn child a very small amount of air passes in at the beginning of inspiration on account of the fact that the air cell walls are closely adhesive. The expansion of the lungs end air cells and the respiratory passages take place gradually. This accounts for the fact that respiration at first in the newborn child is not double but single, that is, consists of only inspirations until expansion of the lungs, air cells and air passages takes place when we find the normal respirations consisting of inspiration and expiration.

CHAPTER V.—ALIMENTATION.

SECTION I.—Introduction.

Alimentation includes those processes through which matter taken into the body becomes assimilated to the tissues and the fluids of the body and the waste matter afterwards is excreted from the body. The different solid and fluid substances necessary for the body nutrition constitute what we call food. The object of taking food, therefore, is to secure the nutrition of the body tissues. This food matter including the O taken in during inspiration passes through certain chemical changes, these chemical changes acting as a source of energy and in time of waste is excreted from the body in various forms. This food matter, therefore, provides for the energy of the body. Alimentation, therfore, supplies the matter for the tissues and also the energy for the body as a whole. In the interehanges between the matter introduced into the system and the system itself, energy is evolved by means of which the bodily function is performed. Thus, alimentation is aprocess consisting of a great number of stages all these stages representing certain actions that are necessary in the maintenance of the tissues and also in the maintenance of the bodily organs and the body as a whole. This process of alimentation must be understood because from the Osteopathic standpoint the lack of nutrition or the failure to perform the nutritive functions forms one of the main causes of the abnormal and the diseased conditions of the body. In fact it forms the main cause of diseased conditions because these alimentary processes are at the basis of the formation of the blood. The tissues of the body receive their nutriment and their O from the fluid which circulates through the whole system whose formation and changes through which it passes, represent the different processes of nutrition. Each of these nutrient processes may be said to include subsidiary processes but they are all united together, in the discharge of one main function, this function being the formation of the blood, its circulation and the process of blood purification.

The living tissues of the body in the performance of their functions pass through certain physical and chemical changes which result in the operations taking place in connection with metabolism of the human body. Alimentation represents a number of processes, each process representing some action having in view the normal maintenance of tissue and body function. This represents an interesting study from the standpoint of disease because where disease exists the nutrition process is at fault. The physical signs of weakness and emaciation indicate the failure of nutrition to perform its proper work. In some cases the fault may be in the food, for the food must be of the nutritive kind in order to be assimilated to the body substance. In other cases the fault lies in the processes through which the food passes, possibly in the blood formation or in the mechanisms of digestion or circulation. In other cases the secretory and excretory systems do their work imperfectly, thus permitting the presence of waste substances in the body that are dangerous to the system.

The physiology of alimentation is most important, therefore, in order to reach an ideal conception of food in its purity and its adaptability to the system, and in relation to the processes through which the food must pass in order to be made ready for assimilation to the body. Alimentaty derangements must be remedied, therefore, along two lines either on the basis of proper diet, or on the basis of proper alimentary actions. How does nutrition of the tissues take place? All the tissues of the body receive their nutriment from the blood that circulates freely in all tissues. To this we must add the oxygen brought into the system in respiration. The proper food elements in connection with the blood depend upon the principles of dietetics. Food, whatever the food may be, differs very materially from the blood and its elements. Hence, certain substances, either in solid or fluid form enter the body to be subjected to certain physical and chemical changes which constitute the digestive process.

In order to the carrying on of digestion, certain actions and processes are necessary for the breaking up of the food, and for its passage to the various glands which secrete fluids, into contact with which food must be brought in order to prepare it for absorption. When it has been acted upon by the various juices, it appears in the soluble form of chyme so that it can pass into the blood or into the lacteals. The chyle passes through the mesentery to the receptaculum chyli, from whence it passes along the thoracic duct to the blood. In this way the blood receives by absorption new nutritive supplies to which is added the oxygen from the respiratory process. For the process of blood formation, blood corpuscles are introduced from the blood glands, these blood corpuscles being held in the fluid. Under the mechanism of the circulation the blood is carried throughout the body bringing these nutrient elements to the different tissues of the body. The blood is receiving new supplies of nutriment, and also collecting the waste matters from the tissues. These waste elements cause the blood to become impure, so that these impurities require to be given off in the form of excretion. The organic functions of the different organs. although distinct, are not independently so. The blood, for example, is a bearer of oxygen and the nutrient matters, at the same time being the bearer of the waste matters. Similarly the liver is the organ in connection with whose cells the formation of the bile takes place. and also the metabolism which is connected with secretion. In the discharge of all these functions there is the setting free of energy in the form of heat and of mechanical work, all the organs of the body being concerned in this liberatiou of energy and heat. In this way nutritive processes lie at the basis of all the activities of the body mechanism and are therefore of great importance.

SECTION II. Diet.

As the body is made up of various proximate principles it is evident that the food which is to nourish the body, must contain or yield similar proximate principles.

The parts of the food which are digested and used by the body are called alimentary principles. An adult, in order to maintain life and health, must use a certain quantity of food daily. The waste is constantly going on in connection with the physical and psychic changes depending upon activity. In a person who is growing a larger amount of food is necessary in order to

furnish matter for the new forming tissues of the body. As the food stuffs are in an insoluble form and differ from the matter of the body tissues conversion requires to take place in order to fit them for use in nourishing the body. The food is subject to great variations from place to place and from year to year, but when all these complex foods are analyzed they are found to consist of certain specific substances which have been reduced to classes. In order to estimate the nutrition value of food it must be analyzed in order to find the constituents contained in it. In order to understand the digestive process we must carefully consider the chemistry of the foods made use of. The proximate principles of the food are: 1st, Water. Too little water in the system causes thirst and too much water causes plethora. Water may be regarded as the medium in which the various chemical tissue changes take place. The amount of water present in the system appears to influence the activity of the tissue changes, for by increasing the amount of water taken in, the amount of nitrogenous waste matter excreted is increased to an extent beyond that which can be explained by the increase of fluid, increasing the facilities of excretion. Water should be clear and free from odors. It should be fresh and palatable, due to the presence of salts and carbonic acid. Spring water is rich in oxygen from the atmospheric air and carbonic acid from the earth. These are said to exist to the extent of 10 to 20 C C of oxygen and 5 to 25 C C of carbonic acid per liter. Distilled water is tasteless. Rain water has no saline substance and hence it is soft, containing carbonic acid, ammonia and some other acids. Water from certain springs contain large quantities of carbonic acid, sulphur, etc.

In water there are mineral substances including the carbonates, sulphates and chlorides. The hardness of water depends upon the lime and magnesia contained within it. Good water should not have more than 20° of hardness, that is, 20 parts of lime to 100,000 parts of water. Water containing organic matter should not be used. Micro-organic subrtances may be found also in the water. Water is absolutely essential to the body as the tissues must have a certain quantity of water to sustain life. If the water falls below a certain quantity which varies in different persons and in different conditions there is a waste in the body.

2d. Salts. Mineral substances are necessary in the foods in order to promote the nutritive processes and for the purpose of nourishing the body. When these salts are absent the health is endangered. The chief salt is chloride of sodium found in all the tissues of the body and in its fluids. In the body excretion it is estimated that from 18 to 20 grams of sodium chloride are excreted daily, and this amount should be supplied daily to the body. If a diet consists of no salts albumin is usually found in the urine. There is not sufficient common salt in the food stuffs, hence, salt must form an element of food. If potassium chloride is used instead of sodium chloride the urine if found to contain very little sodium chloride, the blood and tissues retaining it. Part of the sodium chloride also goes through a chemical change that supplies chlorines in order to form hydrochloric acid for the gastric juice. Potassium salts are also necessary in food. These are found in the blood corpuscles, muscle and nerve tissue, while the sodium salts are found in the liquids. Small quantities assist the circulation of the blood raising the blood pressure and assisting the heart in its normal contractions. Lime salts are also necessary for the nutrition of bony tissue. Iron is found in connection with hæmoglobin of the blood. Most of these leave the body in the same form as they are introduced, playing some important part in the process of nutrition, and then being excreted. These are of value not so much for the chemical changes which they are subject as in connection with the metabolism of the body.

3d. Carbo hydrates. Among these are starch found in potatoes, arrowroot, cereals and in the leguminous vegetables. It is found in small oval granules, possessing different degrees of resistence to water penetration. Cane sugar is found in connection with the cane and the beet, and in some vegetables such as carrots, turnips and watermelons. Grape sugar is found in fruits, in honey, in wine and beer. In addition to these, there is milk sugar, muscle sugar and cellulose. All the carbo-hydrates become absorbed as sugar in digestion. If the diet is rich in earbo-hydrates, the urine excreted is lessened, because the carbo-hydrates are easily oxidized; hence they are used up first by the body. They have no nitrogen and they are destroyed in the body, and from them energy is set free which we find in heat and work. They form the bulk of all diet.

4th. Fats. The fat in animal food consists of three substances, stearin, palmitin and olein; the latter representing the fluid fat, such as oil and the two former, the solid fat such as butter and lard. If an animal is fed on fat alone, the excretion of urea is less than if the animal receives no food at all, indicating that if much fat is present the proteid substances are less likely to be changed in metabolism. There is no nitrogen in fat and hence the fats have greater value as a source of heat and energy than the carbo-hydrates for they are less easily digested and less easily subjected to destruction in the body. Their chief physiological value is, that the fat can be stored up in the body.

5th Proteids. There are two kinds of albuminous substances. (a) Animal such as caseine (milk) myosin (muscle) and albumin (egg and blood.) (b) Vegetable, such as the albumin in wheat and legumin in peas and beans. Albuminous matter is not found so largely in vegetables as in animals. These albuminous substances form the chief substance in the metabolism of nutrition because there is a large amount of proteid in the blood and in the tissues. The proteids whether animal or vegetable are practically the same. Physiologically they furnish the matter for the formation of new tissue and for the repair of old tissue and also as a source of body energy. Because the proteids consist of nitrogenous substances, since the fats and carbon hydrates do not contain nitrogen. Hence proteid is necessary to form new tissue. If the food contains no proteid the tissues would soon waste, hence the proteids and water are the most essential for existence and the other foods are accesories to these. Among the proteids are classed also the albuminoids. One of the chief albuminoids is gelatin. It is not found in the raw foods but we find it in such cooked foods as soup. Like the proteids they contain nitrogen. They cannot, however, take the place of the proteids, their value being that they are nitrogenous, although differing considerably from the pure nitrogenous foods.

6th. Gases. Oxygen may be regarded as a food. Its passage into the blood and the tissues takes place in respiration.

7th. In addition to these certain condiments and beverages are used as food accessories. These stimulate the appetite and promote digestion if taken in moderation and under proper restraints. Alcohol, although in one sense a food, is not a very suitable food. Lieib gstates that alcohol is decomposed in the blood into ethyl, acetic acid, oxalic acid, CO_2 and H_2O. There is a small quantity exhaled through the lungs and excreted by the kidneys. It is said to be oxidized to the extent of 96 per cent, this oxidation producing heat. It also diminishes heat by interrupting the metabolism

in the tissues and lessening the oxidation of fatty substances and carbo-hydrates finally reducing the animal heat. It diminishes proteid metabolism as is evident from the diminution of urea excreted. In small quantities it excites the digestive mucous and also acts as an excitant by diffusion of circulation and the nervous system. In digestion it is not only unnecessary, but hurtful unless used in very small quantities.

The wines contain in addition to alcohol, pigments and organic acids. The character of the wine depending upon the acid that prevails. In wine there is also sugar some traces of proteids and gum. In brandy there is in addition to alcohol oenanthic ether, in rum butyric ether which gives it its odor, in gin juniper oil and in whisky when free from alcohol there is a malt flavor. In the malts we find alcohol, sugar, glutin, dextrin, together with bitters aromas and salts. In beer we find 70 to 80 per cent of water, 2 to 10 per cent of alcohol and 2 to 5 per cent of sugar, 2 to 10 per cent of dextrine and ½ to 1 per cent of carbonic acid. From the hops it derives its bitters, fats, lactic acid and salts. Vegitable acids such as vinegar and acid fruits taken in moderation act as a stimulant in salival and gastric secretion being changed into carbonic acid in passing through the body being excreted as carbonates in the urine. The stimulant condiments taken in small quantities such as pepper, mustard, spices, etc., locally stimulate the mucous membranes and aid the flow of saliva and gastric juce, but digestion may be performed without these. Tea, coffee, cocoa, coca all contain an active alkaloid along with other substances acting as a stimulant upon the nervous system actively increasing the sections and lessening the activity of the waste of tissues. These alkaloids are all related to xanthin. They also contain other substances which are of Physiological value. For example, coffee has a large quantity of aromatic substance, tea a large quantity of tannin and cocoa a large quantity of fat and albumin. Tea also contains iron, maganese and sodium and etherial oil. Coffee contains potassium salts. Tea and coffee act as stimulants to the nervous system and have no after effects of depression like alcohol, relieving feelings of fatigue. This is especially true of coca, the extensive use of which enables persons to undertake long and fatiguing journeys.

A healthy diet must first contain all the proximate principles found in the body or substances capable of yielding all these proximate principles. 2d. Include a sufficient proportion of these substances varying somewhat with the age and condition of the person, the work performed and the climate. 3d. Have a certain sapidity or flavor, in order to promote the appepite and digestion. 4th. These substances must be digestible in order to be nutritive, the indigestible substances being not only lacking in nutritive value but producing an interference with the digestive and excretive organs. Life cannot be sustained upon one of the proximate principles or upon food yielding only one of these principles. There are experiments that have been made in which animals and also human subjects have been fed upon a single proximate principle the result being fatal or injurious to health. A normal diet is one found containing a certain proportion of food of a certain composition necessary for the maintenance of life. Experience and usage have led people to adopt certain diets, and the results of their experience furnish the only means of selecting a proper food diet on a correct basis. Food includes those liquid or solid substances necessary for the nutrition of the body. In the body tissues certain processes of metabolism are necessary to sustain vitality. Chemical changes take place and certain substances are formed which are thrown off as waste matters. This daily loss takes place in connection with the lungs, the kidneys, the skin and the other excretions. Food is necessary to make up for this loss. In the case of an adult working moderately, there is a daily loss by the lungs of about 900 grams of CO_2 or 245 grams of C; by the skin of about 9.15 grams of CO_2 or 2.5 grams of C; by the kidneys about 30 to 36 grams of CO_2 or 9 to 10 grams of C; in the fæces about 15 to 20 grams of C. This represents a total of from 270 to 280 grams of C excreted from the body daily. In the urine there is about 30 grams of urea excreted daily or 14 grams of N. In the other nitrogenous matters excreted from the body there are about 5 grams of N excreted daily, making a total of about 19 grams of N excreted daily. There are also excretions of O and H and various salts, but the chief elements are the C and N because food from a dietetic standpoint depends largely upon these elements. This represents a total loss of about 1,000 grams of matter aside from the water that is thrown off. In addition to this energy is being expended, this energy assuming the forms of motion and heat. This energy is estimated as amounting to over five million foot pounds. The energy represented by the heart action daily is about 50,000 kilog. meters by the activity of the muscles of respiration 12,000 kilog. meters, by the activity of the ordinary muscles 125,000 kilog. meters and the body heat 620,000 kilog. meters representing the total of about 807,000 kilog. meters of energy exhausted daily. This energy must be compensated for by the food supply and by the O of respiration. The changes taking place in the body result in the setting free of energy in the form of heat and mechanical work. The larger amount of the energy takes the form of heat. Even during the inactivity of the muscles, these chemical changes are constantly taking place. In the contraction of muscle more than ¾ of the energy assumes the form of heat, the remaining ¼ taking the form of work, even a part of this latter being in the case of work also converted into heat. This heat supply arises in connection with the oxidation of the food materials, this oxidation taking place in connection with the O absorbed, combining with the CO_2 and the H_2O.

The energy of the body thus converted takes the form of potential energy, these foods being derived originally from plant life built up in connection with the energy of heat-producing bodies, such as the sun. This potential energy under the influence of active body metabolisn becomes kinetic energy. The combustion of foods outside the body gives an approximate estimate of the amount of energy available in the case of certain food. In connection with any substance, it is necessary to determine the energy of the foods as admitted to the body, and also the elimination of waste from the body. This must be replaced by metabolism between the food and the O of respiration. The food supplied to the body during the process of alimentation has, therefore, a most important bearing upon life, functional capacity and health.

The first law of dietetics that we have already referred to, that a suitable diet must provide the proximate principles of the body or foods that will produce these. This is true equally for the plants and animals for civilized and uncivilized people. The general dietary principles have been derived from experiments upon the feeding of animals. In the normal adult the chief consideration in dieting is to provide nitrogenous and non-nitrogenous matters with sufficient salts and water to sustain the body condition. If proteid substances are used alone, a much larger proportion must be used than in the case of the mixed diet. It is questionable if in the human subject life could be long sustained normally, on such a diet on account of the

greater activity of the digestive process in digesting proteid alone and on account of the greater increase of activity in the excretory system. Hence, the general conclusion from this standpoint of hygiene is that there must be a mixed diet consisting of proteids, fats and carbo-hydrates. The ratio between these three chief food elements depends upon the experimental value of the different kinds of food. It is on this basis that the iso-dynamic equivalents made use of by Moleschott are estimated. Voit estimates the ratio of nitrogenous to non-nitrogenous foods as from 1 to 5, this calculation being based on the amount of food in the dry condition. In addition to this the food may be digestible or indigestible. Some foods digest easily and others with difficulty. This can only be determined by experiments in the use of foods in animals. This gives to meat food great nutritive value because only a small per cent is lost, whereas, in vegetable food usually a large per cent escapes digestion and absorption. Various attempts have been made to fix an ideal diet that would meet all possible necessities of the bodily system. Moleschott taking as his basis the daily loss of an individual as we have found it already amounting to about 19 grams of N and 280 grams of C has suggested as a dietary 120 grams of dry albumin, 90 grams of fat, and 350 grams of carbo-hydrates, making in all about 19 ozs. of solid food. According to the estimates of energy on the basis of the colorimetric method, this would produce by oxidation normally a little over one million kilog. meters (one kilog. meter equals 7.233 foot pounds) yielding more than sufficient energy to sustain life, on the basis of the energy expended as given before, considering that complete oxidation does not take place in the body. Experience has shown that dietary variations are necessary for different people, according to their employments or manners of life. Those actively employed in occupations calling for muscular exertion require more food than those engaged in the lighter occupations. This has been brought out chiefly in connection with prisons and reformatories, much larger diet being required when active work is performed.

An ordinary diet of solid food should contain proteid 120 to 130 grams, fats 80 to 90 grams and carbohydrates 350 to 450 grams, and salts 30 grams, representing a total of from 580 to 700 or a little over 20 to 25 ozs. of solid food. In addition to this about 20 to 25 ozs. of water is necessary in connection with the food for cooking purposes, as ordinary food contains about one-half of its weight fluid and from 70 to 80 ozs. of water in addition as a special food element. According to the scientific estimate, a soldier is furnished daily 18 ozs. of bread, 20 ozs. of meat and 16 ozs. of vegetables in addition to 70 ozs of water, and some coffee as a stimulant. The analysis of the composition of various food stuffs indicates that bread, oat meal, peas, cheese, beef, including mutton and veal, fish and eggs are rich in proteid. Rice, arrowroot, potatoes are rich in carbohydrates. Butter, cheese and pork are rich in fats, these being arranged so far as the composition is concerned so that deficiency in one can be made up by others. There are said to be two methods of selecting a proper food diet. 1st. To find out the per centage composition of the articles made use of, estimating the amount by weight required to yield the necessary proximate principles. 2d. To make a selection of food on the basis of Moleschott's estimate that 19 grams of N and 280 grams of C are necessary to supply the daily loss. In this last case it is necessary to estimate the proportion of C to N in the various articles of food. The food is not taken in the form of the proximate principles but in combined articles of diet like bread. In order to estimate the ideal diet it is necessary, therefore, to estimate the proximate principles as found in the various composite foods. In order to have an adequate measure of the vital necessities it is also necessary to estimate the dynamic value of the different foods. This can be done by the calorimetric method in which an estimate can be formed of the amount of heat generated from a given weight of a certain substance or substances, taking into account the fact that complete oxidation does not take place in the system in connection with most of the substances, the amount of energy furnished being less than its estimated amount theoretically. Experiments in regard to the use of certain diets have confirmed these ideas in regard to the distribution of the food elements and their nutritive value. A normal diet therefore, consists of the three great food elements, proteid, fat and carbohydrates, the last being always in excess of the other two. The body may be sustained on the proteids alone, but this is at the expense of the body mechanism because more labor is necessary and the foods are more costly. The fats and the carbohydrates are nearer akin to each other, the fats being converted to sugar and the carbohydrates furnishing the fats necessary for the body when the fat is absent from the food.

In making an estimate of the amount of food necessary in a normal diet three additional circumstances must be taken account of. 1st. Age. 2d. Climate. 3d. The kind of employment. 1st. Young persons and those growing rapidly need more food in proportion to their size than adults, in order to assist the metabolism of the rapid bodily growth. Old people need less food than middle aged and active people, and females less than males:

	Proteids.	Fats.	Carbohydrates.
Children of one year..........................	20	30	60
Children of fourteen years......................	70	36	250
Adult (man)..................................	100 to 110	70	500
Adult (woman)..............................	80 to 90	60	400
Old people....................................	70 to 90	60 to 70	300 to 400

Some think that the size of the body to a large extent determines the amount of food necessary. In general it is said a small body requires less food, but this is subject to the same exception as in the case of body heat, namely: That the metabolism is really greater in the smaller body, the surface being relatively larger, and therefore demanding more food for body metabolism. 2d. Climate. The chief element in climate is that of the temperature. When the body is exposed to a cold bracing atmosphere, the body metabolism increases on account of nervous stimulation producing an increased appetite.

Greater amounts of food are therefore required in cold climates. As the metabolism of the body uses up more carbonaceous matter the food rich in fat elements is the most suitable. This leads to the use of large proportions of fatty substances which by the oxidation process becomes converted into heat. If the bodily system is subjected to a high temperature the metabolism is lessened, although the results are less noticeable in this direction than in the case of cold, chiefly because the temperature of the body tends to maintain its normal heat chiefly by an increase of the amount of heat lost. This leads to the conclusion that more food is required in the hot climate than in a temperate climate, chiefly fluid in character, in order to compensate for the continuous loss by perspiration. Differences in climate to a large extent, however, are compensated for by artificial arrangements, such as clothing, and the supply of heat by air as in the heating apparatus of the house. This, however does not wholly compensate for the metabolic changes and hence in hot regions as com-

pared with the cold the normal diet will be maintained about the same, except that in the hotter regions an increase in the carbo-hydrates and in the colder regions an increase in the fatty substances taken as food is required. 3d. The work done by different individuals is the last element to be considered in connection with the determination of diet. The amount of work modifies the amount of food required in the case of those engaged in the lighter avocations as compared with those in active employments. One who is engaged in hard manual labor requires a larger and more varied supply than one who is not active muscularly, particularly as the amount expended in energy is not taken from the amount of heat liberated, the increased energy in the work being accompanied usually by an increase in the heat set free. Muscular metabolism does not necessarily require an increase in the proteid matter. In muscular labor the muscular condition and capacity, at least from the standpoint of available energy, must be considered, but the capacity for work depends upon the other organs of the body, particularly the nervous system, the lungs and the heart, the nervous system perhaps more drawn upon for energy than any other part of the body. Therefore, whatever diet would be suitable for the body normally would also be of the greatest advantage during muscular activity, provided the activity is increased in such proportion as to meet the general drain upon the system. In the case of mental work this is even more true for the expenditure of energy in this case is minimal except in so far as it bears upon the loss and the increased loss in the entire system. The close relation of all parts of the body is brought out very clearly in the effect which severe mental work has as it draws upon the metabolism of alimentation. Hence the most suitable diet for brain work is not one that would stimulate or nourish the brain because this would result in more or less irritation, but a diet that will keep active the juices of the body in connection with digestion and secretion. In making a selection of food we must consider first the amount of energy that may be yielded by the materials. This represents certain proteids, fats and carbo-hydrate substances. 2d. This energy must be present in such form as to be rendered easily available, in other words the food must be digestible and this digestive process must be such as not to interfere with metabolism of the system. But a substance really valuable for nutrition is one that can be easily assimilated to the system. Various experiments have been made in order to discover what per centage of the food used remains undigested and hence unappropriated by the system. This percentage, of course, depends upon the manner of cooking, on the individual capacity and to a certain extent upon the nature of the meal of which it forms a part. For example, in rice and white bread it is estimated that 4 per cent. in meat and eggs, 5 per cent; in Indian bread or corn, 7 per cent; in milk and peas, 9 per cent; in potatoes 11 per cent; in black bread 15 per cent remains undigested. This would represent the amount of these foods unnutritious and disadvantageous to digestion.

In addition to this the process of digestion may vary in the case of different food stuffs. The same substances found in the different articles of food may even in the alimentary canal pass through changes that are quite different. Proteid matter may be broken up into leucin or changed into peptone; hence, digestibility of food means not only the amount relatively taken up in the alimentary process, but the nature of the changes that take place during the alimentary process. Hence the chemical composition of food does not furnish an answer to the physiological question of its value or the value of its component elements. Food substance may be either animal or vegetable. The proteids from the animal and vegetable source seem to pass through the same or almost the same changes in the alimentary process. The same may be said of the fats and extractives. Hence, from a physiological standpoint all that can be said as to the relative merits of vegetarian and animal diet bears upon the question of the quantity of the proximate principles and the proper proportion of these principles in animal and vegetable diet. Various experiments have been made in the use of a strictly vegetarian diet. As a result it is found first, that a much larger vegetarian diet is necessary to yield the same amount of proteid referred to as a normal diet, namely, 120 to 130 grams. However, it has not yet been definitely settled how much proteid matter is absolutely necessary in order to sustain life. 2d. In vegetarian diet there is a marked increase of the carbohydrates and a diminution of the amount of fats. This seems to be a disadvantage to the system, kept up continuously for a length of time. 3d. In the vegetarian diet a large proportion of the food is indigestible and hence is lost to the system, being given off as waste matter. The waste, therefore, is more in amount in the vegetarian diet than in the animal diet. As excretion is one of the active functions of the body a certain amount of excretion is necessary in order to sustain the normal function and assist in metabolic changes. This does not seem to be compensated, for however in the case of vegetarian diet since a larger demand is made upon the alimentary system in the form of labor and the increased volume of diet passed through the system lays the system open to more foreign substances which may materially affect its vitality. For these reasons vegetarian diet would seem to be less satisfactory than the mixed dieting that includes animal food.

In the case of the human subject there is not needed any special dieting for the purpose of increasing the amount of adipose tissue. The nature of the food has less effect in this case than the general characteristic of the individual animal organism. The same dieting in the case of two persons may produce opposite results; one person becomes fat and the other lean. The chief fat producer is the carbohydrate. In the case of animals fattened for butchering, this is done by converting cheap vegetable carbohydrate into animal fat. This process is aided by resting the system so as not to exhaust the energy of the system unless to the extent necessary for the metabolism of the body. Anti-fat treatments are more important physiologically. This may be accomplished by increasing normal dieting the amount of proteid and lessening the fats and carbohydrates. The reason of this is found in the fact that proteid matter increases the body metabolism, more rapidly destroying the proteid matter and hastening the oxidation process. The Banting plan is to increase the proteid diet to such an extent as to exclude all or almost all fat and carbohydrate substances.

This is, however, unsatisfactory and even perilous to the functional life because it requires such an increased activity on the part of the organism to decompose and get rid of excessive proteid that there is danger of collapse. To diminish the fats and carbohydrates at the same time to increase the amount of proteid together with an increase in the bodily exertion, so as to set up and continue freely the metabolic processes is the most satisfactory method. Daily exercise even to the extent of fatigue aided by Osteopathic treatment, to aid digestion and promote the metabolic processes, will materially help this by producing a very large metabolism. In body metabolism a number of conditioning circumstances require to be considered. Muscular effort increases food consumption, but it is a matter of dispute what food element is affected. It has been pretty generally agreed that muscular activity draws not only upon the proteid matter, but in some cases almost entirely upon the non-proteid substances. If the supply of food is abundant, particularly of non-proteid, that is the fats and carbo-hydrates, there will be no increase, or at least, only a very

small increase in the proteid metabolism, during active muscular effort. In the case of CO_2 it is found that a much larger amount is given off during muscular activity than during comparative rest. If it is true that there is an increase in the amount of nitrogenous matter excreted and a very large increase in the CO_2 discharged from the body, then the energy of muscular activity must arise from non-proteid matter. The muscle itself is a proteid substance but the changes taking place in liberating the energy are largely, if not wholly, confined to non-proteid matter. In muscular activity there is a large consumption of glycogen, or of the saccharine, derived from it. It has been shown that a muscle subject to fatiguing labor demands much more sugar, the power to do severe muscular work being increased by the consumption of large quantities of sugar until the non-proteid elements are exhausted, when the demands upon proteid matter increase. During sleep when the muscles are much less active or resting, having lost to a certain extent, their normal muscular tonicity, the CO_2 discharged and the O absorbed, are very much lessened, while there is no marked change in the metabolism of proteid matter. In the case of animals deprived of food, the metabolism depends upon what is found in the body, consisting of stored up fats and carbo-hydrates, especially the sugar. The sugar is first exhausted, and later the animal lives upon its own fat and proteid. It is found that in an animal feeding upon its own substance, the greatest loss is in the muscles, whereas, the largest consumption is in the fat, which is found to be almost entirely gone after death from starvation. It has been found on examination of animals that died from starvation, that almost no appreciable loss had taken place of the heart, the brain and the spinal cord, although these organs were constantly active during life. They sustain their life, however, at the expense of the other tissue substances. In the case of energy assuming the forms of heat and work done, the supply is derived from metabolism of proteid, fats, and carbo-hydrates which become oxydized under the influence of O, CO_2 and H_2O, being formed and excreted from the body. Thus, the energy derived from the food is determined by comparing the food taken into the body with the excretions from the body. The process of oxidation is a complex one, involving the liberation of energy together with the formation of urea, CO_2 and H_2O. By the combustion of the different elements of the food substance, a ratio is formed representing the interchange taking place in the liberation of energy called the isodynamic equivalent. This ratio between fats and carbohyrates is put at 1 to 2.3. The object of the food supply is to furnish to the body sufficient proteid and non-proteid matter together with salts and water to sustain the body balance between proteid and non-proteid matter.

In the case of man it is doubtful if this body equilibrium can be maintained by the use of proteids alone so that an average diet for the human being must be composed of proteids, fats and carbo-hydrates. The normal ratio between proteids and non proteids necessary for daily diet is placed at 1 to 5 in the solid material apart from the necessary quantity of water found in connection with the substances used and the quantity of water necessary for the body. In order to secure a proper diet we must consider the proportion of those substances in the different articles of diet, pre-supposing that these substances are digestible and that account must be taken of digestibility from the standpoint of the individual organism. In the case of a healthy person normally active experience aided by appetite may be taken as a safe guide. In abnormal conditions the regulation of diet depends upon Physiological and Pathological conditions. In milk of an ordinary kind we find about 87 per cent water, 3.4 per cent of proteid, 4 per cent fat, 5 per cent sugar and a small per cent of salt, .7, including potassium phosphate and calcium phosphate with a small amount of chloride of potassium, sodium chloride and iron. Milk is a good diet for growing persons but is not sufficient for adults, because the balance of the nitrogenous elements cannot be sustained on such a pure diet. Cream butter yields about 87 per cent of fat, 8 to 9 per cent of water and .75 or .80 per cent of albuminous substances. When combined with foods that yield proteids and carbo hydrates it is very valuable as a diet. Butter milk is milk deprived of its fats, but contains sugar, casein and salts. Cheese contains fat and casein, from 10 to 20 per cent of the former and 25 to 30 per cent of proteid. It is valuable as an addition to other foods poor in proteids and fats. Animal meat of average leanness contains about 75 per cent of water (fowl about 70 per cent and pork 72 per cent); of proteid 20 per cent (fowl 22 per cent and pork 19 per cent); of fat 5 per cent (fowl 4 per cent and pork 6 per cent; of carbohydrate .7 per cent (fowl 1.3 per cent and pork 6 per cent.) The flesh of fowls and birds is richest in proteid. Raw flesh finely grated is almost wholly digested but its value for nutrition may be counteracted by the introduction into the body of foreign living bodies endangering life as in the case of trichinosis. Meat may be prepared in various ways by roasting, stewing and boiling. Meat should be cooked to a temperature within the meat itself ranging from 56° to 70° C. Salted meat loses a small per centage of proteid, of the extractives and of phosphoric acid passing into the salt brine. The amount lost, however is small unless where the meat is kept in brine for a long time when the potassium salts are lost to a large extent. The flesh of young animals is richer in gelatin, the variation being according to Liebig in veal 50 parts in a thousand and in beef 6 in a thousand. Meat roasted openly before a fire develops a layer on the surface keeping the juices inside. In the process of roasting, about 25 per cent of the weight is lost. If meat is placed in cold water there will be dissolved out of it a small per cent of proteid and extractives and most of the saline matter. If beef is boiled then the salt and the extractives with gelatine are found in the fusion. Even after long boiling there remains in the meat about 20 per cent of the salts and about 15 per cent of proteid. To prepare what is called beef tea, the meat should be placed in cold water and gradually boiled. By placing the meat suddenly in hot water there is a coagulated layer formed around the meat, thus preventing the juice from being dissolved out of the meat. Beef tea is nutritious because it contains salts, gelatin extractives and a small quantity of proteid. Its chief value is that of stimulation due to the extractives; its nourishing quality being found in the gelatin, fat and albumin.

In Liebig's meat extract there is about 20 per cent of water and 80 per cent of solids, its action being rather stimulating than nourishing, due to the presence of phosphate of potassium. Eggs are found to contain much nutritious matter, about 27 per cent of solid and 73 per cent of fluid. The chief constituent of the solids are albumin, vitellin to the extent of 3 per cent and palmitin, olein, cholesterin and lecithin about 11 per cent together with, about 1 per cent of the salts of potassium and choloride and a very small proportion of iron and sugar. As found in the egg these substances are very easily digested. When hard boiled they should be boiled for at least 20 minutes slowly. They should be finely grated so as to come readily into contact with the gastric juice. They are more easily digested if soft boiled, poached or raw. Vegetable foods are less easily subjected to the digestive juices on account of fact that the nutritious elements are bound up with cellulose and combined with large quantities of indigestible matters. The proteid in vegetables does not differ much from animal proteid. The salts, however, are different, being chiefly those of potassium and magnesia phosphates. When the cereals are broken so as to divide the cellulose it is found that the flour contains about 12 or 13 per cent of albumin, 65 to 67 per cent of carbohydrates, the bran being very indigestible on account of the large per cent of fibrous substance, 30 per cent. The flour when made into bread, in the case of white bread, contains 35 per cent water, 7.1 per cent of albumin, 1 per cent of fat and 55.5 per cent of carbohydrates and 1 per cent of salts. Indian corn bread is rich in carbohydrates and poor in albumin. Barley and oat meal flour are nutritious on account of the combination of albumin and carbohydrate. Bread consists of a mixture of flour with water under the influence of a ferment. By fermentation the starch is converted into dextrin, CO_2 and alcohol; by the formation of gas the bread becomes looser and lighter in formation. When the bread is baked in a high temperature fermentation is arrested and the bread be comes very digestible. Each adult requires about 1½ kilog. of bread to furnish the necessary proteid matter. Among the leguminous plants and vegetables, peas and beans are said to contain over 23 per cent of albumin, 50 per of carbohydrates, 1½ per cent of fats, while potatoes contain 75 per cent of water, only 2 per cent of albumin and 20 per cent of carbohydrates. Rice and potatoes being very deficient in proteid, large quantities are required to be taken to be of much value in nutrition, 2 kilog. of rice and 4½ kilog. of potatoes, as the proportion of carbohydrates is large, the excessive use of these is liable to produce acid ferments that interfere more or less with digestion. Along with this when used in moderation there should be used some foods rich in albumin such as fish and eggs. The vegetables, cabbage, cauliflowers and turnips are rich in the potassium salts, although not very nutritious as foods and hence form a good combination with corned meats which are deficient in potassium and rich in the sodium salts. These elementary foods are not suitable for use in their raw condition, hence, cooking is required in order to make them easily digestible, and to give to them a flavor. In cooking food, water, condiments and heat are the three necessary adjuncts in the preparation of food for coming into close contact with the bodily juices and assimlation into the system.

Food, we have seen, includes all that is necessary for the sustenance of the body. All foods originally spring from the earth, so that while we distinguish between an animal and a vegetable diet, the source of food depends upon the same origin. In the passage from the inorganic to the organic, we find the process of preparation going on which ultimately brings the food nearest to the human system. This change takes place primarily in the vegetable kingdom. All the vegetables are not suitable for food and many of them are poisonous. Even in the same plant all the different parts are not equally useful, hence man requires a knowledge of these plants, their properties and their adaptability for human use. Some portions of the vegetable kingdom unsuitable for man's use are well adapted for the food of animals, and thus in the economy of nature, the lower serves the higher nature providing a sufficient amount and variety for all. The bee gathers the honey from sources inaccessible to man, and the cattle feed upon rough materials unfitted for human use, converting the food into tissuse, food easily capable of assimilation to the human system. In this way the inorganic becomes adapted to man's necessities. The animals could not live without vegetables, each being indispensible to the life of the other. The vegetable is nourished upon the soil and the air, carbon being extracted out of the air and stored up in its substance so that it becomes the animal food. In the same way the vegetable lives and grows upon the waste of the animal kingdom, the decomposition of animal bones, the CO_2 exhaled from the animal breath furnishing the food matter of the vegetable life. The food substances are either inorganic or organic, the former representing substances from the mineral kingdom, such as salts, and the latter representing the food derived from vegetables and animals. Nature thus provides for man a sufficient diet, sufficient both in quantity and variety, and if man fails to utilize the food thus furnished for his use he neglects the first law of existence, self preservation. The hygienic conflict between vegetable and anti-vegetable food is as foolish as it is useless, because nature designed both vegetable and animal food for man's use. Proper hygiene lays down the following rules:

1st. That an attempt to sustain life upon any one substance to the exclusion of others results in failure because the body is imperfectly nourished and life is thereby shortened. Dogs have been fed exclusively on a single food and have soon died of starvation. A donkey fed on rice alone died in 14 days. Dr. Hammond fed himself on 1½ lbs. of gum and on another occasion on 1½ lbs. of starch with water daily with the result that the fever increased to such an extent that in a few days he had to abandon this diet. Later he fed himself on 1½ lbs. of albumin and found that diarrhoeic conditions and the amount of albumin in the urine became so dangerous that he had to give it up on the ninth day.

2d. The absence of necessary elements of diet results in diseased conditions. It has been found that where persons have been deprived of vegetables for a long time, skin diseases like scurvy become prevalent. Where the food is poor it has a depressing effect rendering persons liable to all kinds of diseases. There is no condition that favors the spread of a plague so efficiently as a poor and unvaried diet. This is evident from the accounts we have of the poor and their scanty food during the great European plagues.

3d. A diet to be healthy ought to be varied. The same diet from day to day becomes, not only monotonous to the sense of taste, but develops unhealthful conditions. While we do not think that a diet should be purely vegetarian no diet should be without vegetables. Variety may be secured not only by the use of various foods but also by variety in cooking. The constitution is often undermined by the lack of variety.

Dr. Stark, one of the most promising of English Physiologists in the 18th century, became a victim in this way to experiments upon himself. For 44 days he lived on bread and water; for 29 days he took only bread, sugar and water, and for 24 days he lived on bread, olive oil and water, the result being that he died on account of the damage done to his constitution by limiting his diet to these simple foods. A sufficient variety in food and a sufficient quantity of food thus represent the two great essentials of a healthy diet. For an average adult there should be from 88 to 112 ozs. of food and water distributed as follows:

From 48 to 56 ozs. of water and salts; from 24 to 40 ozs. of bread, vegetables and fruits, and about 16 ozs. of meat and fats. This would represent a daily allowance of about 1-24 part of the body weight in the form of food. In regard to the variation of animal and vegetable food, Carpenter reaches this conclusion: that while "a well selected vegetable diet is capable of producing in the greatest number of individuals the highest physical development of which they are capable it may be affirmed with equal certainty that the substitution of a moderate proportion of animal flesh is in no way injurious, but so far as our evidence at present extends, this seems rather to favor the highest mental development."

If we consider the predominence of mind over matter this conclusion will represent a moderate principle in the nourishment of both mind and body. Dr. Richardson, of London, says that animal food should not be taken oftener than twice daily and the amount of animal and vegetable food combined should not exceed 30 ounces daily. Animal food when eaten ought to be fresh and not under-cooked. There is no more fruitful source of disease parasites than meat underdone. This is especially true of pork, the muscles of which are infested with trichina spiralis.

Hunger and Thirst. Hunger is a sensation that is usually referred particularly to the stomach. Physiologically, however, it is due rather to a general want of the whole system. It is usually referred to the stomach because by supplying the stomach with food there is a feeling of relief. It would seem to depend upon the stimulation of the pneumogastrics in connection with the stomach and perhaps the alimentary canal or the intestines. The introduction of nutriment directly into the intestines or of concentrated food substances that do not cause a distention of the stomach or only a slight distention will satisfy hunger. This would indicate that hunger arises not from the stomach alone, but also from the other organs and tissues which demand nutrition. It is intimately connected also with the central nervous system. The division of the pneumogastrics does not produce any change in the feeling of hunger by way of relief. The use of stimulants like tobacco or alcohol lessens or at least puts off for a time its activity, possibly on account of stimulation imparted to the nerves of the stomach through the centers of the brain. The same effect may be produced by mental acts and states. In its origin hunger represents an appetite for food which is not painful. If continued, however, it becomes painful. Hunger is thus one of the forces of nature which tend to the preservation of the body life and indicate the necessity for diet.

Thirst is referred usually to the palate and pharynx representing a local condition of the mucous of the posterior portion of the pharynx. The section of the nerves which supply the pharynx, the pneumogastric, the glosso-pharyngeal and the trigeminal does not diminish thirst. This condition of thirst may originate in the lessening of the quantity of water in the blood or from the stoppage of certain secretions under the influence of certain chemicals, for example, belladonna. It is due to the general want of the tissues and can be relieved by the introduction of water into the blood vessels or into the alimentary system or by the submersion of the body in water. For how long a time an individual can live without food or drink is not known. This will depend upon a variety of circumstances including bodily condition and the amount of waste in the bodily substance, together with the age, condition of life and the surroundings of the body. Normally entire abstinence cannot be sustained longer than 8 or 10 days. This may be extended if water alone is supplied, although in extraordinary circumstances this period has been prolonged for 40 and even 50 days. The entire deprivation of food usually results in death after 20 days. Children and those rapidly growing succumb sooner than adult persons. With a supply of water life may be prolonged with a small quantity of food or even with no food at all, an animal surviving longer upon water than upon any of the other proximate principles. The entire deprivation of water usually results in death in from 6 to 10 days. Indians under the influence of drugs have been known to remain in a trance condition for many weeks. In cases where abstinence is prolonged the individuals become hibituated to this condition, being almost like the hybernating animals. The cold blooded animals like the frog, have been known to live from 8 to 9 months without food. Dogs have been found to live a long time upon water alone, cases being on record in which dogs have lived for four weeks without either food or drink. In some cases there is an excessive appetite, this condition being termed bulimia. It is peculiarly characteristic of certain diseased conditions, such as diabetes and in certain stages of fevers, especially during the convalescent period. The minimum of food necessary to sustain life, cannot be stated because this depends very largely upon the individual characteristics and upon the activity of life. Even the activity of life does not depend upon the amount of food, as individuals have often lived actively upon a very small proportion of food. It is generally stated that most persons take food in excess, this being one of the common causes of gastric derangements and dyspeptic conditions. Hence the advice of hygiene is to modify and regulate the diet in its quantity, as well as in the proper selection of food. During the starvation of the animal there is a constant body loss due to the using up of the tissues.

When the body ceases to receive nutriment it lives upon its own substance, the active organs losing rapidly. The fat stored up in the body is first exhausted, next the blood, its albumin being used up in the tissues. This is followed by diminution in the secretions, the urine becoming acid and the blood watery. The oxidations become less vigorous and the amount of CO_2 given off is diminished. The tissues then lose their power, become weaker in action, the central nervous system being the last to yield to the general dissolution. What is the effect of a modified diet? Deprivation of water arrests the secretion and especially the activity of the kidneys resulting in death very soon Hence water must be taken in sufficient quantities The same is true of salts. If albuminous matter is cut off from the food supply there is a great diminution in the excretion of urea. This becomes more marked if the food is rich in carbo-hydrates. In this case the body metabolism, especially of the albuminous tissue is lessened in activity, less urea being excreted than if no food is taken at all. The carbohydrates in this case use the O supply of the body in the oxidation process, leaving but little of the O for the albuminous matter. If the carbohydrates are cut off and only proteids are given with plenty of water life may be sustained for a considerable period. If fat is given along with the albumin there are different results. If a small quantity of fat is given with a large quantity of albumin most of the albumin is lost in body metabolism. If a large quantity of fat is given and a large quantity of albumin, considerable albumin and fat are stored in the body. These facts indicate that a mixed diet is the preferable one. being more suitable to the bodily system, the proper combination of the different foods yielding most satisfactory results.

SECTION III. Fermentation.

Digestion consists largely of chemical changes taking place in the food in its passage along the alimentary canal. These changes are peculiar on account of the fact that they are accomplished by ferments to which the name of enzymes is given; the action of these being different from other bodies of asimilar kind. Many changes during the digestive process are simply fermentations. Besides the existence, development and reproduction of ferments, are intimately associated with certain diseased conditions. In the fermentation of fluid it becomes either clear or more muddy, throwing off gas and seething with the froth, these representing physical changes. Associated with these physical changes there are certain chemical changes represented by the alcoholic and other substances such as CO_2 found in connection with the fluid and given off from it. There is also a deposit at the bottom consisting of small organisms of a minute character, consisting of unicellar bodies representing the biological change. These processes, including the physical, chemical and biological, were all associated together as phenomena in connection with the ferment which is so called, from the fact that the surface presents the frothing appearance.

These processes must have been known from very early times. The first fact noticed was the frothing or the physical change. In early centuries alcohol, when formed by fermentation, was separated from the water by alchemy. Helmont first suggested that the gas thrown off was the same as we find in connection with oxidation processes, namely, CO_2. It was then found that by the dissolution of the sugar, CO_2 and alcohol were produced. Difference of opinion existed as to the substances formed from the fermentation of sugar, Pasteur being the first to differentiate the chemical substances in connection with sugar includiug alcohol, CO_2 succ inic acid and glycerine. It was early discovered that pure grape juice if boiled and kept free from air did not ferment, the unpurified and unboiled solution fermenting. It was not until comparatively recent times that fermentation was found to be due to certain vegetable cells which are found to grow and increase rapidly in sugar solutions. Many theories have been proposed to explain this phenomenon.

1st. The Berzelian theory was that it was due to catalysis or to the simple fact of the presence of the ferment in the fluid.

2d. The Liebig theory was that there existed no necessary relation between the fermentation and the existence of vegetable living cells. The living cells produce some substance which, as it acts upon the substances to be fermented, produces a motion among the atoms of the substances, giving rise to the boiling or frothing condition. This is simply an extension of the physical theory of Berzelius. Certain chemical changes are produced by the ferment resulting in vibrating movements. Liebig says that "Physiological action would be necessary for the production of these substances" in other words, the living organism undergoes a certain chemical change corresponding with physiological metabolism resulting in the formation of certain substances which produce molecular vibration. For a long time it was thus supposed that fermentation was purely a chemical process.

3d. In more recent times the question has been discussed largely from a biological standpoint; the ferment being caused by the presence of minute organisms. This has been accomplished, especially through the experiments of Pasteur, who spent considerable time in the attempt to cultivate these minute organisms. Thus, we have been led to the vital theory of fermentation according to which these represent germs of life, a particular form of life, or as Pasteur says, "fermentation is life without air," although it is admitted that these organisms assume two forms, aerobic and anaerobic, the one living through the presence and the other through the absence of air. It was first discovered that boiled grape juice if kept in a vacuum did not ferment, but if a single air bubble is permitted to enter, fermentation results.

Schwann admitted an air bubble through a red hot tube and found that no fermentation followed. He concluded that fermentation was due to something in the air and heat prevented fermentation by destroying the substance in the air; hence, physical and chemical conditions seem to favor the growth of the organisms from 20° to 40°C. assisting, above 60°C and below freezing point arresting it. Schwann then attempted to identify fermentation and putrefaction, finding that the air has the same to do with putrefaction as with fermentation.

Helmholtz proved that air is produced by the dissolution of a compound by means of electricity, the air thus produced does not cause fermentation. By placing a bladder filled with grape juice inside a vat of fermenting juice the fluid in the bladder did not ferment, the producing cause being unable to pass through the wall of the bladder. From this and similar experiments it is evident that the organisms in the air are the cause both of fermentation and putrefaction. At this point Pasteur began his researches which have immortalized his name and produced a revolution in the scientific world. He found that each form of fermentation was produced by a different ferment. The alcoholic by the yeast cell, lactic fermentation by lactic acid, etc. He then began to cultivate these organisms in certain fluids which seem germane to their life so that he could localize certain organisms with certain fluids. He found that the ferment producing the butyric fermentation could live and grow in a fluid mixture of certain minerals with sugar, the presence of free air interrupting the fermentation. He found that this applied to some of the other fermentations. It was this that led him to the conclusion that most of the ferment organisms may be ærobic or anærobic, that is, live in the presence or absence of air, but that it is while it is anærobic that it does the fermentation work. When it receives free air it grows and develops as in the case of molds found on the surface of exposed foods, but when free air is excluded it draws O from the substance in which it exists and in this way produces fermentation. This does not mean that these organisms can live without air, for they can produce that air necessary for their life inside the substances in which they are found. They can live without free air as Pasteur has said, extracting sufficient O from the substances such as sugar.

Engleman has pointed out that some of these organisms gather close to an air bubble while others move away from the air bubble. There are some, however, that require O, as the bacteria aceti. Pasteur's final theory is that some O is necessary at the beginning of fermentation, but that when begun free O is not necessary. By these experiments the biological theory of fermentation has been established. Some organisms have been identified in connection with lactic fermentation, the acetous mannite and urine as well as putrefaction and fermentation. Although the fermentations are different and also the ferments, some of the productions of fermentation are alike, for example alcohol; some claim that the increase in the minute organisms in the substances is not the cause of the production of fermentation but the product of fermentation. It has been proved, however that if the fermentation germs do not pass into the fluid, fermentation may be prevented, so that it is possible to completely sterilize certain fluids and substances and so remove anything that could cause fermentation. The manner in which these ferments act is unknown, although it is supposed that these minute organisms produce a kind of ferment which acts on the substances under the process of fermentation. This action is supposed to take place not directly but by reduction. In this case, of course, the absence of O would be characteristic. If O is present it is more likely that the process is one simply of oxidation. If this latter statement is true we can account for some of the results at least of oxidation taking place in the tissues. There are constant molecular changes taking place in the living tissues, these may be partially oxidation changes but where sufficient O is not present these molecular changes may result from fermentation. When H is set free O is also liberated and it acts on the oxidizable substances. Aside from the field of bacteriology to which belong what are called the organized ferments, there are the unorganized ferments or enzymes or the unformed ferments that belong properly to the field of Physiology.

Digestion consists largely of certain processes of chemical changes through which food passes in its passage through the alimentary system.

These digestive changes are effected by means of these enzymes whose action is peculiar. These are substances produced inside animals and plants although not actively endowed with life. When obtained in free solution from organic matter, they are colorless and tasteless. They can be dissolved in water and precipitated by alcohol. They are like the albumin derivatives, but do not contain sulphur. These are distinct from the living germs found in bacteria and are really dead, although they are generated in living substances. Their chemical composition is not known, although they are complex compounds. Some think that this ferment belongs to the albumin derivatives, the solutions of these ferments give the proteid reactions, but this may be due to impurity in the solution. These are usually classified according to their reactions. 1st. Proteolytic; those changing proteid into soluble peptones, proteoses or triptones. In connection with digestion we find the pepsin of the gastric juice and the tripsin of the pancreatic and intestinal juices, the former acid, the later alkaline. 2d. Amylolytic; acting on starch and changing it into a solution of sugar, or sugar and dextrin. In animal digestion we find the ptyalin of saliva, amylopsin of the pancreatic juice and a liver ferment producing sugar or glycogen 3d. Steatolytic or fat separating ferments, acting on the neutral fats and separating them into fatty acids and glycerine by the action of the pancreatic ferment called steapsin. 4th. Inversive ferments, transforming the double into the single saccharines. For example, converting the cane sugar into the dextrose, laevulose and glucose by the action of invertin in the intestinal juice, and possibly to a small extent in the salival juice. 5th. Coagulating ferments, as the fibrin ferment of blood, acting upon the proteids and producing an insoluble clot similar to this, and of the same nature as the rennin ferment of gastric juice which produces curdled milk. The fibrin ferment seems to belong to the class of albuminoids and this has led some Physiologists to suppose that all ferments belong to the same class.

This. however, is incorrect. 6th. Urea ferment, splitting up urea and converting it into carbonates of ammonia. These are found in connection with the deposits of urine. These ferments are the chief agents in the food changes that take place during the process of digestion and hence, form a most important element in considering the digestive secretions. A ferment is a substance that causes change in another substance without itself undergoing that change. This, of course, means that in causing a reaction the ferment is not itself used up. It does not mean that the enzyme continues to exist permanently or that its action is unlimited in extent or indefinite in time. The action of ferment outside of the coagulating ferments is said to be on the principle of hydrolysis. This means that the ferment acts upon the separate molecular atoms producing hydration, causing these atoms to take up one or more molecules of water. The hydrated molecule is then separated so as to form smaller separate bodies. It is not known how this hydration takes place. Some Physiologists have supposed that it was accomplished by catalysis or by the influence of contact arising from the presence of the enzyme. In addition to this it is said by others that the presence of the ferment causes vibrations in the substance among its molecules thus leading to the absorption of the fluid and the breaking up into smaller bodies. Others have said that the ferment produces a chemical reaction, without its undergoing any change itself, acting the part simply of a medium in conveying to the substance the chemical influence. This is not unknown in the field of chemistry as we find in connection with the blood, the hæmoglobin becomes oxyhæmoglobin and after delivering the O to the tissues returning to its original form. Whatever may be the action of these ferments the presence of these ferments in the human body in connection with the juices explains largely the different processes of digestion.

SECTION IV.—1. Digestive Processes in the Mouth and Passages to the Stomach.

Digestion includes all those processes and changes through which the food passes in the alimentary canal, in order to prepare it for entering into the blood by the process of absorption. These changes are the result of several processes to which the food is subjected in its passage through the mouth, the stomach and the intestines. These processes to which the food is subjected are various. In connection with the mouth there are two, mastication and insalivation and there is deglutition in the passage to the stomach. The food is introduced into the mouth by means of the hand or some other artificial means devised for the assistance of the hands. After the introduction of the food into the mouth it is subjected to the process of decomposition accomplished by the movements of the jaws and teeth and later it is mixed with certain fluid secretions. Fluids are introduced into the mouth, passing into the pharynx and from thence to the stomach. It is by inspiration that fluids are sucked into the mouth. If the lips are immersed in the fluid in drinking, inspiration pulls out the air from the mouth, the fluid passing in under the pressure of the atmosphere. If the lips are not immersed in the fluid there is some air that passes in along with the fluid.

The movements in connection with alimentation are dependent upon the action of plain muscles. It is of importance to consider the character of the muscles as these movements depend upon the muscle. Plain muscle in the abdominal and visceral walls is composed of minute cells of varying size and shape. There is no cross striation, the cells being united to form fibers, all running in a longitudinal direction, corresponding with the cell axis. These cell plexuses form sheets of muscle which constitute the visceral walls, the coats being either longitudinal or circular. These cells are bound together by a cement substance, the cells being continuous in their protoplasm and thus affording a continuous path for the wave of contraction. These tissue walls are under the control of the motor nerves, indicating the close connection between the muscle tissue and the nerve fibers. The chief Physiological point in connection with this plain muscle tissue is the slowness of the contraction. It is subject to any kind of stimulation but the latent period is longer than usual, a slow contraction being followed by a slow relaxation. This lengthening of the periods depends upon the absence of cross striation. This however is not sufficient to account for the slowness, as other plain muscle, like the ciliary muscle, contracts more rapidly. This slowness of contraction is of great value in the alimentary canal, permitting of the slow movements of the food contents during digestion. In addition to this the passage of the wave of contraction from cell to cell provides for the contraction in either direction. This, at least, is true of the ureter, although there is no positive proof of its truth in regard to the intestines. These muscles of the intestines are always in a tonic condition, that is, a condition of normal contraction subject to an increase or decrease in the contraction taking place slowly. This characteristic contraction is called peristalsis or the contraction beginning at any point in the wall of the tubular viscus passing along the walls of the tube in the form of

a wave, each part of the tube slowly contracting and then slowly relaxing. Thus, from its entrance into the mouth until it passes out of the body the food is constantly subject to certain movements which act upon the food for the purpose of breaking it up completely, subjecting it to the digestive action. In the alimentary canal we find two layers or muscular coats, a thin longitudinal layer and a thicker circular layer separated by a connective tissue coating. The wave of contraction passing along the circular layer contracting the tube and thus pushing on the contents, the wave passing along the longitudinal layer, following the circular layer wave, helps in the forward movements of the contents and in the return of the tube to its normal size.

1. Mastication is the division of the food and its breaking up by the teeth. The food is cut by the sharp edges of the incisors and canines and ground between the rough surfaces of the molars and bicuspids. The incisors are used in biting off a part of the food, the canines in breaking it up and molars in grinding it. There is a downward and horizontal movement of the lower jaw, the former producing an upper and downward movement of the arches and the latter of grinding. The former result is produced by the alternate downward and upward movement of the lower jaw. The digastric muscle aided by the thryo-hyoid, sterno-hyoid and omo-hyoid muscles which fix the hyoid bone, open the mouth; the genio-hyoid and the mylo-hyoid pulling down the lower jaw; the temporal, masseter and internal pterygoid muscles closing it. The external pterygoids in alternation upon the two sides producing the horozontal action of the under jaw, retraction taking place by the internal pterygoid. The orbicularis oris keeps the mouth closed. The trituri tion of the food between the molars is caused by a kind of rotatory action of the lower jaw, due to the movements alternately of the external pterygoids. The food is rolled about by the tongue which pushes it between the teeth, while the contraction of the buccinator muscles prevents the accumulation of the food between the cheeks and the dental arches. The process of mastication is assisted by the mixture of the food with the fluids. If the mastication is complete the food is ready for digestive action. Complete mastication is very essential in order to prevent derangements of the digestive system. The food is rotated by the tongue backward and forward, the tongue moving around in any direction to suit the action of the food, the tongue keeping in place the food and regulating the mastication.

Mastication is a voluntary action directed by the muscles and also by the nerves. The sensory impressions relative to the position, state and readiness of the food for swallowing are carried to the brain chiefly by afferent fibers of the fifth pair of nerves and the glosso-pharyngeal in connection with the tongue. Motor influences are conveyed to the muscles concerned in mastication by the following nerves. The motor fibers of the 5th in its inferior maxillary branch to the buccinator, the anterior belly of the digastric and the masticatory muscles. The hypoglossal regulates the tongue, furnishing by the descendens noni impulses to the omo-hyoid, sterno-hyoid and sterno-thyroid and by the hypoglossal branches to the genio-hyoid and the thyro-hyoid. The facial motors supply the posterior belly of the digastric, the lip muscles and the buccinator. The reflex center is in the medulla and Pons varolii close to the muclei of the 5th, 7th hypoglossal and glosso-pharyngeal nerves.

2d. Insalivation. During mastication the food is mixed with the fluid saliva, a mixed fluid secreted by the parotid sub-maxillary and sub-lingual glands and by the small glands of the buccal mucous membrane. The saliva is a thickish, transparent, glairy and somewhat turbid fluid with a slight sediment. In this sediment are found flat epithelium cells from the mucous of the mouth, mucous corpuscles probably leucocytes which have escaped into the secretion and spheroidal cells from the salivary glands known as the salivary corpuscles, together with protoplasmic masses with amoeboid movements. The specific gravity averages about 1003 to 1009.

The saliva is alkaline in reaction, due to the pressure of alkaline sodium phosphate, its alkalinity being about .08 per cent. It consists of water with about .5 per cent of solid matter. The solids consist of salts including lime carbonate, alkaline chlorides and the phosphates of lime and magnesia with sulphocyanide of potassium and CO_2 in combination with carbonates. Small quantities of O and N, mucin, albumin and globulin and an unorganized ferment ptyalin of the amylolytic class which has the power of converting the starch into various forms of sugar, dextrin and maltose. Ptyalin when pure by precipitation is a whitish gray powder very soluble in water. The constituents of saliva are in 1,000 parts, 994.15 of water, 2.2 of mucin, 1.4 of ptyalin and albumin, 2.2 of salts and .05 potassium sulphocyanide. Mucin is an important element, producing the viscous character of the saliva. It is formed in the gland by combination of the proteid and carbohydrate. Sulphocyanide is formed by the decomposition of proteids, being one of the products of proteid metabolism. This effect is produced more quickly where the starch is boiled, as boiling removes the celluloid envelope of the starch granules. There are other conditions favoring the ferment power of the ptyalin including a moderate temperature 70° F and the fluid in which the action is taking place being either alkaline or neutral. The various salivary secretions have been secured by the use of tubes in connection with the glands. The parotid saliva is clear and limpid, not viscous. It is slightly alkaline although the first flow is acid, and it yields but little ptyalin and traces of urea. When exposed to air it deposits lime carbonate and becomes milky. The sub-maxillary saliva is viscid on account of the mucin. It is more alkaline and contains ptyalin and sulpho-cyanide of potassium. The sublingual gland secretion is still more viscid on account of the large proportion of mucin with more salts and is very markedly alkaline.

In young children the saliva contains very little ptyalin and this in the parotid gland only. The ferment appears a few months after birth in the submaxillary saliva, after which salival secretion increases in connection with the dentition process. The chief element in saliva is ptyalin. It is found in the human saliva and also in that of lower animals. It is detected chiefly by its action upon starch. The starch is split up by a series of hydrolytic actions. It is found that sugar is formed from the starch, not directly but after passing through several stages, and that the transformation does not take place perfectly, at least when artificial experiments are made In the case of normal digestion the substances when produced are taken away so that the transformation into sugar would be more complete, indicating that maltose is the definite product of ptyalin action. The process of conversion is not known although it seems that the starch atoms take up water then dividing up to form dextrin and maltose, the dextrin again by hydration forming dextrin and maltose and so on till the process is complete. Thus dextrin appears in different forms during the process of insalivation. The action of saliva is more marked if the starch is boiled, the sugar being developed in a few minntes, whereas if the starch is uncooked it takes a much longer time, this being due to the fact that starch is bound up in cellulose so the ptyalin cannot get at it, and that when boiled it has taken up water and is therefore more easily acted on. This shows the value of cooked vegetable foods as opposed to raw vegetables. From what has been said the ptyalin is found to be present in small quantities, its action being dependent upon temperature. It follows therefore, that its action is fermentative.

The function of the saliva is three-fold. 1st. To convert starch into the sugar, glucose and maltose; 2nd. To moisten and soften the food and so to assist in swallowing; 3rd. To keep the mouth moist and so to facilitate articulation. The saliva simply acts upon one substance, starch, converting it into maltose and dextrin about, one half of the starch being changed into sugar in the mouth. The conversion takes place freely at 35° but if the temperature is lower conversion is hindered as is also the case if it rises above 60° C, being entirely arrested at 70°C and at 0°C, the action being most effective at 40°C. The effect of heat seems to be in the ferment rather than in the starch substances. By boiling starch into a paste and putting into it saliva at 35°C the paste will become fluid, the sugar being found in a few minutes, the form of sugar being maltose. Saliva acts most freely in the neutral solution, its normal reaction being slightly alkaline, excessive acidity arresting its activity. Weak acidity or alkalinity diminishing its activity, strong alkaline reaction arresting its activity. The activity is most marked if the saliva is diluted with the digestive substances in the ratio of 1 to 100. If this dilution is largely increased a small quantity of sugar is still converted. Very small quantities of acid proteids will hinder and large quantities will destroy the activity of ptyalin. Hence the formation of those acid proteids retards the action of the ptyalin until it ceases to act at all. Free hydrochloric acid in small quantities .003 per cent almost entirely stops its action and if .005 per cent is present it will destroy the ptyalin. This indicates that ptyalin ceases to act on the food when it reaches the stomach.

The action of saliva upon starch is hindered by the product of salivation, sugar. Hence, the process will be arrested if the sugar is allowed to remain in the starch. If it is taken out as it is formed the process will go on. Human saliva is not very active, its activity being directed to the moistening of food for swallowing. Food remains for such a short time in the mouth that salival action cannot be very complete, so that the chief value of the saliva is to moisten the food and by its viscidity to aid in the passage of the food through the œsophagus. In the case of soluble minerals it dissolves them. In the case of fats it has only a slight emulsifying effect. On proteids it has a moistening effect. The amount secreted by the human subject every day is estimated from 400 to 900 grams. The secretion, however, depends upon the nature of the food. In the case of any dry food where only a small quantity of water is used the secretion is large. This secretion is also increased by speaking and by the sapidity of the food.

SECTION V. Innervation Of Insalivation.

The ordinary flow of saliva is a reflex action. The lingual nerve being the afferent path and the chorda tympani the efferent path for impulses. The food substance stimulates the glosso-pharyngeal and the lingual nerves which convey impulses to a center in the medulla from which efferent impulses pass to the salivary glands.

The efferent nerve to the submaxillary is the chorda tympani. The saliva is drawn from the blood under the influence of the activity of the cells, the amount of the fluid flow depending upon the necessity of the digestive system; hence, when the mouth has no food in it only sufficient saliva flow takes place to keep it moist. When the food or any substances enter the mouth the salival flow commences. The influence of the nervous system on salivary secretion and flow has been chiefly studied in connection with the sub-maxillary glands. There are connected with these glands in the human subject fibers from the facial through the chorda tympani and from the sympathetic. The chorda tympani springs from the facial nerves at the lower extremities of the Fallopian aqueduct passing through the small canal opening on the posterior wall of the tympanum, passing across the tympanum and then passing out of this canal by an opening in the interior extremity of the Glasserian fissure. It passes down along the internal surface of the internal ligament of the jaw connecting with the lingual trunk, the submaxillary ganglion and the blood vessels in connection with the tongue. This submaxillary ganglion is closely related to the lingual branch of the 5th nerve by the anterior and posterior roots, the latter carrying the fibers from the ganglion to the chorda tympani. The nerve fibers run along the duct towards the gland, nerve cells arising especially after the entrance of the hilum into the gland. The nerves enter the gland but how they are distributed in connection with the gland is as yet unknown. The chorda fibers are medulated till they enter the gland, when medulation is lost. The sympathetic also sends out fibers to join this ganglion, arising from the plexus of the facial artery. The blood vessels of the submaxillary gland are connected with the ganglion by means of a number of fine nerves, the nerve fibers reaching the gland along with the arteries of the gland. Several of these small fibers pass to the mucous membrane of the mouth. These fibers are non-medullated and may be traced to the superior cervical ganglion, thence, back to the cervical sympathetic and the spinal cord. If a tube is applied to the sub- maxillary gland a whitish turbid fluid passes out if the tongue is stimulated by some food substances or if the lingual nerve is artificially stimulated. If chemical stimulation is applied to the tongue changes may be made in these secretions, a weak solution of acid producing a clear fluid and an alkaline solution a viscous fluid. These changes are due to nervous stimulation depending upon the nerve to which the stimulus is applied. (1.) Stimulation of the sympathetics produces contraction of the arteries, a slowing of the circulation, the blood passing from the gland being of a deep dark color. The secretion is diminished, the saliva becoming thready and viscous and containing numerous corpuscles and protoplasmic lumps together with mucin. If the stimulation is long continued the saliva becomes limpid very like the chorda secretion, indicating that the chorda and sympathetic secretions are similar in their nature. Previous to the effect produced upon the secretion after the application of the stimulation there is a brief latent period from 2 to 20 seconds before the change takes place in the saliva. The fibers are the vaso-constrictor and probably act by the stimulation of the local ganglia. (2.) Stimulation of the chorda tympani at the peripheral end after its division causes the dilatation of the arteries, a quickening of the circulation, bright arterial blood passing into the veins, a copious watery secretion with free salivary corpuscles and protoplasmic masses with salts. Thus the chorda is a vaso-dilator fiber and increases the secretions. The fibers are so far as the vessels are concerned, vaso-dilators, but it is believed that some are also distributed to the secreting cells of the gland for if atropin be administered

the stimulation of the chorda tympani will still cause the dilatation of the blood vessels but no secretion of saliva. In this case the atropin paralyzes the secretory glands but not the vascular fibers of the chorda tympani. The nerve fibers in all probability dilate the blood vessels by the inhibition of the local ganglia. (3.) If the lingual nerve is cut and stimulation is applied to the central end the secretion increases very much. This secretion, however, will not increase if before stimulation the chorda tympani is also cut. (4th.) If the glosso-pharyngeal is stimulated the effect is more noticable than in the case of the chorda tympani, this being the principal afferent nerve in secretion. If the mucosa of the stomach is stimulated by the fistulous introduction of food there is a salival flow. The same result will follow stimulation of the pneumogastric or the sciatic. These are reflex in connection with the central nervous system.

From this we conclude that there is a nerve circle including sensory fibers of the lingual, a center in the brain and fibers of the chorda, producing secretion and the salival flow by reflex action. If the sympathetic, the chorda and the lingual are cut and stimulation applied and the mucous lining of the mouth, the secretion increases, indicating that the submaxillary ganglion acts as a subordinate reflex center. Normally, submaxillary secretion is limpid and the chorda activity is excited by stimulus applied to the lingual and glosso-pharyngeal nerves, or the sensory fibers of the 5th in the mouth and tongue, or the olfactory branches or the vagi branches to the stomach, all of these producing a watery secretion. In the same way flavorous substances, the masticatory action of the jaws or the presence of some solid substances in connection with the tongue produce the same flow of watery secretion. The secretory center is in the medulla close to the rise of the 7th and 9th cranials. The sympathatic fibers arise from the same point. If the lingual trunk is divided above the junction of the chorda and if the tongue is stimulated there will be no flow of the saliva. This indicates that the center must be above this point. The center in the medulla is near to the vasomotor center. If the upper part of the brain is removed, leaving intact the medulla the salival flow will continue, if there is sufficient afferent stimulation. If the medulla is destroyed the salival flow ceases. If direct stimulation is applied to the medulla the salival flow will continue, The efferent impulses pass from the center in the medulla either by the chorda tympani or by the sympathetic, although some claim that no efferent impulses pass through the sympathetic. The salival flow, therefore, depends upon efferent impulses brought the gland along the chorda tympani. By the stimulation of the chorda peripherally after division the secretion flows freely, the saliva being watery with only a few plotoplasmic substances and salivary corpuscles. The blood flows freely in the arteries, capillaries and veins, the venous blood being almost arterial in color and producing a pulsation in the veins, this being due to the fact that the blood, flows quicky and does not lose its O.

Thus, the stimulation of the chorda produces dilatation of the blood vessels in the gland and the salival flow. The difference between the chorda stimulation and the stimulation of the sympathetic is that the former gives rise to dilatation of the blood vessels and the free flow of watery saliva, while the later constricts the arteries and gives rise to a diminished flow of viscous saliva. This indicates that the blood supply is not the direct cause of the flow of secretion, although it may be connected with it in some way. In the case of the parotid gland there are two kinds of nerves, one from the central nervous system passing along the auriculo-temporal branch of the fifth and the other originating in the cervical sympathetic. The former nerves are vaso-dilator and the latter vaso-constrictor. This center in the medulla may be stimulated not only by afferent impulses from below but also by impulses arising in the cerebrum, arising from a psychic influence connected with the thought of a savoury meal. This influence may be either accelerator or inhibitory, in the former case producing a free watery secretion in the mouth, and in the latter case, parching the mouth. Secretion in the submaxillary gland is not a process of filtration but takes place internally in the gland determining blood flow to the gland. Secretion is not arrested by the pressure becoming greater in the gland than in the arteries. Ever after decapitation the secretion will continue in the gland indicating that the salivais not simply filtered through the gland from the blood but is produced in the gland cells. In confirmation of this it is claimed by some that the nerve terminals are found in the gland cell protoplasm or in the neuclei of the cells, at least they seem to be intimately connected in some way. This nervus connection with the cells has been traced in the liver. In connection with the chorda tympani two different kinds of fibers exist, secretory or accelerator or inhibitory. The use of atropin produces paralysis of the accelerator without effecting the inhibitory. If then stimulation is appliedto the chorda, no secretion takes place, though the blood vessels are dilated. Thus, thedilator fibers have not been effected at all; the secretory fibers have been effected. If the chorda is divided after the lapse of a day the Wharton duct begins to discharge the liquid secretion called the paralytic secretion which continues to flow for several days, after which it ceases, the gland beginning towaste. If but one chorda is cut, this watery secretion will flow from both glands. This is supposed to be due to the venosity of the blood stimulating a local center, this flow continuing during the vitality of the local ganglion. During the secretry process the gland temperature is raised from 1° to 2°C producing an increase in the flow of venous blood leaving the gland as compared with the arteral blood received into it. The changes in the gland also produce certain electric influences, a change taking place between the normal gland and the gland under stimulation, resulting in a negative variation. During the resting of the gland the hilum of the gland is positive to the rest of the gland. If the chorda is stimulated the hilum becomes negative after a latent period. If the sympathetic is stimulated the hilum becomes negative to the rest of the gland. Secretion and flow are thus dependent upon three factors.

(1.) Blood supply. The secretion increasing or diminishing according to the supply of the blood. (2.) Nervous impulses. There is an increase of the secretion by the nerve activity upon the gland cells. The blood supply is under the control of the nerve fibers, one set increasing, another set decreasing supply. This nerve impulse is under the control of the local reflex center or the centers in the central nervous system. (3.) The activity of the gland c rpuscles. This means that it is due not simply to blood pressure. This is shown by the fact already referred to in reference to the stimulation of the fibers of the chord a tympani in connection with the submaxillary gland when the system is under the influence of atropin, It can also be shown by ligaturing the duct of the gland when secretion will still continue, although the pressure inside the gland is greater than that inside the blood vessels. The submaxillary ganglion appears to be a kind of secondary reflex center for the submaxillary gland If the nerves that connect the tongue with the central nervous system are divided, substances applied to the surface of the tongue cause a flow of saliva. The nerve fibers to the sublingual gland come from the lingual division of the 5th and also from the sympathetic as well as from the submaxillary ganglion. Nerve fibers passing to the parotid gland

from the glosso-pharyngeal by the otic ganglion and the inferior superficial petrosal, the immediate connection with the gland being through the auriculotemporal. The glosso-pharyngeal through its tympanic branch passes to the internal tympanic going through the petrous ganglion. Passing along the interior wall of the tympanum, it passes out at the upper part becoming the small superficial petrosal nerve which is found in the upper part of the petrous division of the temporal bone, passing downward to the otic ganglion. The otic ganglion gets fibers from the inferior maxillary branch of the 5th, from the sympathetic and the glosso-pharyngeal through the small superficial petrosal. Thus, the nervous connection of the parotid is similar to that of the submaxillary gland.

Heidenhain has tried to explain the secretory process in the gland. In the cell we find the cell substance and also the secretion, each cell being subject to the influence of trophic fibers which produce the chemical protoplasmic changes in the cells and also of secretory fibers which are concerned in the act of secretion. In the cranial nerves, we find secretory fibers and very few trophic fibers so that the stimulation of these nerves produces a free flow of watery secretion. In the sympathetic nerves we find trophic fibers and very few secretory fibers so that the stimulation of these fibers does not produce any flow or only a slight flow of secretion, the secretion being thick. If the stimulation is long continued the secretory fibers are strongly affected so that the solid matter of the secretion is used up. A weak stimulation on the other hand, increasing the protoplasm of the secretion.

This indicates a double process taking place in the gland cell, an anabolic and a katabolic process, each of these processes being dependent upon nervous connection so that the salival flow depends very largely upon the nervous connection with the gland. As distinguished from insalivation mastication is a voluntary act under the direction of the muscular sense and the sensation. It is not, however, purely voluntary as the paralysis of the nerves controlling the tongue, takes away the influence of sensations which aid so materially the voluntary act.

SECTION VI. Deglutition.

After the process of mastication is complete by breaking up the food and mixing it thoroughly with saliva, the food is formed into a circular bolus and conveyed to the stomach by the process of deglutition which consists of a succession of complex muscular movements. This transmission takes place through the pharynx and the oesophagus. The pharynx is a muscular tube reaching from the base of the skull to the lower edge of the cricoid cartilage. The oesophagus below is continuous with it. The soft palate projects backward into it, and is an envelope passing backward from the hard palate forming the conical shaped uvula with two lateral folds, the anterior and posterior pillars of the fauces between which we find the tonsils. Between the anterior pillars is the isthmus of the faceus. In connection with the pharynx we find the three constrictor muscles and the stylo, and palato-pharyngeal muscles. The palato glossus found in connection with the anterior pillar of the fauces and the palato-pharyngeal with the posterior pillar. The levator palati elevates the soft palate. The palato glossus and pharyngealmuscles depress it. In all there are seven orifices into the pharynx, two from the nose, two eustachian tubes, the isthmus of the fauces, the laryngeal opening and the opening to the oesophagus. The oesophagus begins opposite the 6th cervical vertebra, passing through the diaphragm and entering the stomach opposite the 10th dorsal. The calibre of the oesophagus while resting, is star shaped. The upper part of the oesophagus is striated muscle which gives rise to the quick movements of this part of the oesophagus, whereas, the lower part is untriated, the movements of this part being much slower.

Deglutition includes three periods, the passage of the bolus through the isthmus of the fauces, the passage through the pharynx and the passage through the oesophagus. After the bolus reaches the isthmus there begins the involuntary and reflex movement. There is a backward movement of the tongue and an elevation of its central part by the contraction of the stylo-glossi muscles. The tongue at the same time changes its form, sending the bolus back to the soft palate. The bolus then goes through the isthmus and the anterior pillars, contracting, and thus preventing it from returning to the mouth. It includes the passage of the food from the mouth to the stomach. It may be divided into three stages

1st. From the mouth to the isthmus of the fauces. This is the voluntary stage during which the bolus is by the movements of the tongue carried back to the fauces. When the bolus lies on the upper surface of the tongue the elevation of the tongue forces it back to the soft palate. It is voluntary in the sense that the tongue can be freely used to do this It requires, however, a moistening of the food. As soon as it passes within these fauces there commences and is rapidly completed the 2d stage, through the pharynx. This stage is spasmodic and is of the nature of a reflex action. The tongue is jerked upward and backward by the stylo-glossi muscle and thus, the food bolus is thrown into the lower part of the pharynx. The pharynx is the common tube for the food and air, and hence, more rapid movement of the food is necessary during this stage. At the same time other movements take place by which the openings leading from the pharynx except that into the oesophagus are closed, and in this way the bolus is prevented from entering them. Various steps in this process are noticeable. (a.) The muscles of mastication fix the lower jaw, pressing the arches of the teeth against each other. The pharynx is pulled up and forward by the palato-pharyngeal and the stylo-pharyngeal muscles, the constrictors and the muscles from the lower jaw to the hyoid bone. The pharynx ascends, accompanied by the ascension of the larynx. The constrictor muscles also contract from above downward, pressing the bolus against the soft edges of the palate and the tongue, carrying the bolus into the oesophagus as to prevent regurgitation of the food into the nose. The palata-glossi muscles contract and produce a narrowing of the anterior arch of the fauces. preventing the bolus from returning to the buccal cavity. Having entered the pharynx certain movements are necessary in order to prevent its passage into the nasal cavity to the trachea and to carry it into the oesophagus. (b.) The soft palate is raised by the levator palati muscles which prevent regurgitation of the food into the nose, while, by the contraction of the palato-pharyngeal muscles the two posterior pillars of the fauces are made to approach one another like the blades of a pair of scissors, leaving between them a narrow passage that is filled up by uvula. In this way there is formed a sloping shelf which cuts off the bolus from the posterior nares and the eustachian tubes.

It is a matter of dispute whether the orifices of the eustachian tubes are open or closed during deglutition. The posterior surface of the soft palate I think, is directed back toward the wall of the pharynx occupying a horizontal position and almost closing the eustachian tube. The mylo-hyoid muscles contract rapidly thus lessening considerably the buccal cavity, the bolus being quickly sent from the mouth through the pharynx and the œsophagus into the stomach, the contractions taking place in the œsophagus and pharyngeal walls being supplementary to drive down the remnants of the bolus. (c.) As the tongue is jerked upwards and backwards the hyoid bone with the pharynx and larynx is carried upward and forward. Hence the base of the tongue presses the epiglottis down over the superior aperture of the larynx. The closure is completed by the constriction of the muscular fibers connected with the epiglottis. At the same time the rima glottidis is closed, the arytenoid cartileges and the true vocal cords being brought close together, the cushion of the epiglottis fitting in between the cords. The general view is that the epiglottis presses down on the laryngeal opening, closing it and protecting the respiratory passages. If the epiglottis is taken out normal swallowing continues. According to some recent cases the epiglottis becomes erect in swallowing although this is not accepted as correct. By these means the orifices leading from the pharynx are closed with the exception of that into the œsophagus. The œsophegus and the lower part of the pharynx are somewhat raised to meet the descending bolus by the contraction of the stylo-pharyngeal and palato-pharyngeal muscles forcing the food downward and thus preparing for the 3rd stage. During this stage, therefore, the buccal cavity is closed by the tongue pressing upon the soft palate and by the constriction of the muscles of the anterior pillars of the fauces. The nasal cavity orifices are closed by the raising of the soft palate, of the uvula and the constriction of the muscles of the posterior pillars of the fauces. The tracheal opening is closed by the constriction of the vocal cords, the elevation of the larynx and the lowering of the epiglottis over the larynx. In this way a clear and well marked passage is cleared for the food through the pharynx.

3d. In the oesophagus, this is the involuntary stage. The constrictors of the pharynx close over the food which enters the oesophagus along which it is carried by peristaltic contraction. When the food enters the oesophagus the pharynx falls downward, the openings of the mouth, the nasal cavity and the glottis being opened and the fragments of food being carried down by a succession of oesophagal contractions. The oesophagal movements are undulatory; and hence, they are called peristaltic. The circular contraction originating in the pharynx passes into the oesophagus, being first communicated to the transverse coats of the oesophagus and then assisted by the contraction of the longitudinal coats, the movements being always directed downward. The muscles of the oesophagus are found to contain striated fibers in the upper part, and unstriated fibers in the lower part, peristaltic action being the same in both except that in the striated fibers it travels much more rapidly. These peristaltic movements may be carried out by the muscles without any assistance from the nerve fibers, terminating in the muscles and apart from any stimulation from the central nervous system, as these can be seen in the organs when removed the body.

But in the living body the connections are so close with the nervous system as to make the connection of nerves and muscles inseparable in the production of peristaltic action. The contractions do not originate and are not carried out by the walls of the tube alone and thus transmitted from segment to segment in the tube. The efferent impulses pass from the medulla to the different regions of the tract. Hence, if a part of the œsphagus is excited the contraction will commence and go down the oesophagus to the cut portion and will proceed to go down the lower part, crossing the gap, indicating that nervous stimulation passes to the oesophagus in all its parts from the central nervous system. Persstaltic movements of the lower portion of the oesophagus can be aroused by irritating the pharnyx. In the production of these peristaltic movements of the oesophagus we find the pharyngeal afferent nerves, the superior laryngeal, the pharyngeal branches of the pheumogastric, the branches of the 5th and the branches of the glosso-pharyngeal. The center of peristaltic action is in the medulla being a portion of the deglutition center, the efferent impulses pass from the center along the pneumogastric, passing by the recurrent laryngeal to the upper part of the pharynx and through the pneumogastric laryngeal plexus to the lower part. If the vagus trunk is divided deglutition in the last stage through the oesophagus is difficult. If the If the pheripheral end of the cut trunk is stimulated, then the peristaltic contractions are noticeable. Where the œsophagus unites with the stomach at the cardiac orifice in the last part of the oesophagus the circular fibers continue in a tonic contracted state, especially when the stomach is filled. This contraction of the lower end of the esophagus acts as a closure sphincter, preventing the regurgitation of the food from the stomach. When the food reaches this point the center which controls this part is inhibited, so as to dilate the orifices and permit the passage of the food into the stomach which comes with sufficient force to press through the small opening, producing a sound over the upper region of the abdomen. These movements of the oesophagal walls are very much like those found in the stomach and intestines. The muscular coating of the alimentary canal consist of two layers, the external thin layer arranged longitudinally and an interior thick layer arranged transversely with a layer of connective tissue in the middle. When constriction takes place in the transverse layer the contraction is transmitted downward, causing contractions of the circular layers. This causes the contraction of the tube pushing forward the contents. In the case of the longitudinal layer a contraction of any portion of the tube helps forward the contents by drawing the tube over the contents immediately above. These contraction movements are transmitted all along the walls of the tube. The transverse and longitudinal contractions are supposed to take place at different times and not simultaneously, because simiItaneous contractions would tend to neutralize each other. It is supposed that longitudinal contraction takes place first and accompanies transverse relaxation and vice versa, the thick coat of the transverse representing the stronger force, the thinner longitudinal coat assisting the movements forward. These conjoint movements produce a writhing and twisting in the walls along the tubes of the intestines, which is called peristaltic action. All these movements in deglutition are induced, if not produced, by the stimulation arising from the food or liquid coming into contact with the tongue and fauces. These movements are aided by the insalivation of the food and the closure of the mouth, as it is very difficult to swallow any substance with the mouth open.

These movements originate from stimulation by the food or drink brought into contact with the posterior portions of the tongue and the anterior portions of the fauces. This is greatly assisted by insalivation of the food, as dry food is almost impossible to swallow. The same difficulty in swallowing is experienced when the mouth is kept open. By experiments it has been found that deglutition lasts about 6 seconds; about 3 seconds representing the movements of the lower pharynx and oesophagus and three seconds the upper pharynx. If the respiratory passages are not closed the food passes into the larynx, producing excitation, resulting in choking sensations. This irritation produces expiratory movements, followed by a cough which drives out the foreign particles.

According to Kronecker and Meltzer soft food is forced through the pharynx and the oesophagus by the quick and powerful contraction of the mylo-hyoid muscles. When the food lies on the surface of the tongue, by the pressure of the tongue against the palate, it is forced back to the back part of

the mouth, and prevented from coming forward. At this point under the contraction of the mylo-hyoids the food is forced through the pharynx and oesophagus. The movements of the hyo-glossi muscles move the tongue back and downward, pressing down the epiglottis over the larynx and pressing the food downward. The food bolus, according to their conclusion, reaches the opening into the stomach in 1-10 of a second. The action of the pharyngeal constrictors and the oesophagus peristalsis does not assist deglutition but takes place after the swallowing of the food, the object of which is to clear down the fragments, and if the food bolus is detained to push it down more slowly through the pharynx and the oesophagus. According to these Physiologists the food bolus when it has passed to the lower end of the oesophagus stops, on account of the tonic contraction of the sphincter until the peristalsis reaches that point so as to relax the sphincter and thus permit the passage of the food into the stomach. The peristaltic wave reaches that point about 6 seconds after the entrance of the food into the mouth. Instead of there being two regions in the oesophagus as we find in the old theory, according to these investigations there are three regions, the upper, middle and lower, so that there are three contractions in the peristaltic movements. These three contractions together with the pharyngeal constrictors and the mylo-hyoid muscles are the five segmentary contractions producing deglutition in normal circumstances. This represents a new and simpler theory of the deglutition which as yet has not been fully confirmed. If confirmed it will simplify very much the physiology of deglutition.

The Nervous Arrangement of Deglutition.

Deglutition as a whole represents a reflex action complex in character. It is impossible without some stimulation of the mucous coat of the fauces. The first stage represents a voluntary action, the second stage is said to be partly voluntary and partly reflex. The movements, however, may take place involuntarily and during unconsciousness. In the last stage it is purely involuntary, the will having nothing to do with the action and the movements concerned. It is a complicated reflex action, therefore, involving many muscles, all these muscles co-operating to produce definite results, the connections and the results being very definite. The nervous connections associated with the act of deglutition are, 1st, afferent sensory fibers carrying impulses to the centers; the glosso-pharyngeal in connection with the tongue and the pharynx, the branches of the 5th pair of cranial nerves from the palate and the tongue and the pharyngeal branch of the superior laryngeal portion of the pneumogastric from the upper laryngeal orifice. 2d. The center of reflex action lies in the medulla and the Pons Varolii. If an animal's brain is removed leaving the medulla, deglutition can be induced by stimulating the fauces, even if the animal is unconscious. If the medulla is removed deglutition is impossible. Various centers have been localized in the nucleus of the 7th, the pneumogastric and the glosso-pharyngeal, the 5th and the hypo-glossal, all those being closely grouped together. The deglutition center is higher than the center of respiration, so that when the lower part of the medulla is injured the deglutition process may go on unimpaired. Possibly this center like others, cannot be confined to a small local area but covers the region representing the nuclei of the origin of efferent fibers to the muscles of deglutition. 3d. The afferent motor nerves carrying impulses to the muscles of deglutition are the hypoglossal to the thyro-hyoid, genio-hyoid, hyo- and stylo-glossi muscles and the intrinsic muscles of the tongue, the glosso-pharyngeal and the pharyngeal plexus formed from the pharyngeal branch of the pneumogastric and the sympathetic to the constrictor muscles of the fauces and pharynx, the palato-glossal and the palato-pharyngeal; the 5th pair of nerves by the mylo-hyoid branch of the inferior maxillary to the anterior belly of the digastric and the mylo-hyoid muscles; the 7th or facial to the posterior belly of the digastric to the stylo-hyoid muscles, the glosso-pharyngeal to the stylo-pharyngeal muscle and the laryngeal branches of the vagus to the laryngeal muscles.

SECTION VII.—2.—Digestive Processes That Take Place in the Stomach.

The stomach is a special organ of digestion. The stomach has three coatings, the mucous, muscular and serous layers. The mucous lining consists of epithelium, tunica propria with tubular glands, muscularis mucosæ, and the sub-mucous tissue. The epithelium consists of the columnar cells secreting mucus, the mucin being found contained within the protoplasm at the upper surfaces. There are two kinds of glands found in connection with the stomach, the cardiac and pyloric glands, simple glands opening into the surfaces of the mucous membrane. In the cardiac glands we find two kinds of cells, the principal or the hidden cell and the parietal or oxyntic cells; the latter being largely marginal cells found in the body and neck of the gland and the principal cells in the tube. It is in the marginal cells where the hydrochloric acid of the gastric juice is secreted. The pyloric glands have the columnar cells. During fasting from food the fundic cells are shrunken. After taking food the cell enlarges; this enlargement being removed at a later stage of digestion. In the pyloric gland during digestion the cells become darker and more granular. The muscular coat consists of two layers of smooth muscle fibers and the serous coat consists of peritoneal membrane. The three coatings, the longitudinal circular and the oblique represent the action of the stomach. The circular coat lies between the other two and is more important. At the end of the fundus the circular coats are thin but increase in thickness towards the pyloric end, forming a very massive structure of great importance in the stomach movements. The vascular mechanism of the stomach consists of minute arteries distributed on the serous coating entering the muscular layers and then penetrating the submucous coat in a dense capillary mesh work from which delicate vessels pass to the tunica propria forming plexuses at the glandular base. Minute capillaries pass from these plexuses around the gland orifices. It is from these that the small veins arise, passing to a venous plexus in the tunica propria.

The lymphatic arrangements of the stomach are found in connection with minute tubules passing out between the glands, uniting with the lacteal plexus at the base of the glands, these passing to a larger system in the submucous coat. Here arise lymph vessels with valves passing to the muscular coatings, the muscular tissue being freely supplied with lymphatics. The lymph vessels which have collected the lymph then pass along the serous coating to the mesentery passing between the coatings to the mesenteric glands. The nervous connection to the stomach is furnished by the branches of the pneumogastric ane of the sympathetics from the solar plexus. The sympathetic fibers arise from the spinal cord, psssing through the thoracic ganglia to the splanchnics and the solar plexus. These reach the stomach as non-medullated fibers. The vagi as they reach the stomach are also non-medullated, the fibers of the vagi being motor. Numerous fibers, chiefly non medullated constitute plexuses underneath the serous coating

from which the fibers pass into the outer muscular layer forming plexuses between the two muscular layers. From these plexuses great numbers of fine fibers pass into the submucous coat again forming plexuses from which fibers pass to the glands. Thus the vascular lymphatic and nervous connection is very complete. When the food reaches the stomach it is subject to the following influences:

1st. A temperature of about 104°F

2nd. Certain movements and compression. These movements take place by rythmic contractions of the muscular coatings, the object being to bring food directly into contact with the juices and when digested expel it into the duodenum.

3rd. The action of the gastric juice secreted by the glands in the mucous membrane.

4th. Absorption takes place in the stomach. The temperature will be considered in connection with the gastric juice and absorption after we have finished digestion. 1st. The movements : Stomachic movements have two objects. 1st. In order to subject the stomach contents to the influence of the gastric juice and 2nd, to throw the food when partially digested into the first portion of the lower intestines. Hence a distinction has been drawn between two stages in these movements called the churning and propelling movements. When the stomach is empty it is curved from above downwards, all the muscles being in a tonic condition of contraction. The stomach is lessened in size by contraction, the cavity being almost closed up, the mucous membrane being unfolded in connection with the circular fibers. When food reaches the stomach and when it is filled the stomach begins to relax except at the pyloric orifice, the cardiac orifice opening as food enters. The stomach rotates on its long axis so that the greatest curvature is carried forward, the anterior surface is carried upward and the posterior surface downward. Thus the stomach extends in the direction where there is freer action towards the frontal abdominal walls. The muscular fibers of the stomach contract the on food and cause it to circulate, the current passing from the cardiac orifice along the great curvature and back again by the lesser curvature, while at the same time other currents carry the food which is in contact with the mucous membrane of the peripheral portion to the deeper parts of the stomach and vice versa. These actions give rise to rotatory movements of the contents of the stomach, the rotations taking place successively at short intervals and last for a few minutes. These movements are of the nature of peristaltic contractions producing the churning movements. The contact of the food with the mucous membrane of the stomach produces a mechanical stimulation which is strengthened by the chemical action of the gastric juice. These movements result in complete mixing of the food with the fluids, the movements becoming more marked as the digestion proceeds. In this way the food is thoroughly churned and its complete admixture with the gastric juice is secured. The contraction of the gastric muscular fibers is at first slight and becomes increasingly active as digestion proceeds, that is as the stomach gradually empties. While digestion is going on the pyloric orifice is closed by the sphincter. As digestion proceeds there are propulsive movements occuring at intervals. These consist of contractions of the circular fibers beginning at the antrum of the pylorus, passing downward and propelling the food downward. From time to time the pyloric sphincter relaxes, due to the inhibition of the pyloric contraction, a portion of the food passes from the stomach into the small intestine (duodenum). This movement is sudden, in the form of a very quick contraction, being actively marked at the pylorus.

The action of the sphincter seems to depend on the contents of the stomach. for undigested parts of the food do not pass through the pylorus but are driven back again into the stomach. The churning and propulsive movements usually drive the fluid part of the contents in the form of chyme into the duodenum, the more solid parts remaining in the stomach for the further action of the gastric juice. The food substance is gradually conveyed to the duodenum, the indigestible elements being the last to pass from the stomach. Some indigestible elements do not leave the stomach, causing the disagreeable feeling in the stomach. The presence of the food does not cause the movements as when the stomach is fullest the movements are at the lowest. It is rather acidity that produces the movements by stimulation. These movements take place at intervals of 15 minutes until the food is all digested and emptied into the small intestine. The nervous mechanism of the stomach is supplied by the pneumogastric and the splanchnic nerves. If the sympathetic is stimulated there do not result any movements. If, on the other hand, the pneumogastric is stimulated, active movements occur in the cardiac portion, particularly if the stomach is dilated. If the sympathetic or pneumogastrics be divided these movements are not suspended, indicating that the ganglia which are found in the plexuses of the abdominal walls act as centers of activity even after separation from the central nervous system. If the splanchnics are stimulated these contractions cease, their action being inhibitory, stimulation producing dilatation of the contracted stomach and relaxation of the sphincters, the vagi nerves in connection with the sphincter causing the contraction. Thus, the movements in the stomach walls are due to local influences arising from impulses sent out from the ganglionic centers. Impulses conveyed along the pneumogastric excite these movements to become more vigorous whereas, impulses conveyed along the splanchnic sympathetics exercise the inhibitory force. Recent experiments indicate that there are also inhibitory fibers in the vagus and the sciatic nerves. The stimulation of the central ends of these nerves inhibiting the tonus of the stomach. These movements under impulses are regulative as we have seen that the stomach movements are almost purely muscular.

If the stomach is subjected to a shock produced either by striking with a flat instrument, or by the applications of induction shocks, there will arise certain contractile movements. These movements as undulations being transmitted along the abdominal walls. The stomach movements thus do not depend upon the connection of the stomach with the central nervous system. If the extrinsic nerves are divided even, after the removal of the stomach from the body, these movements continue, provided the temperature and moisture are sustained. This indicates that the stomach acts automatically, that is, independently of the nervous stimulation. The movements are like the heart movements, that is, muscular. The antrum pylori seems to be the chief cause of the movements of the stomach, originating both the pyloric movements that drive the food contents from the stomach and the movements that keep the contents in motion in the stomach. According to some, there are no movements of the fundic end, the fundus remaining in a normal tonic condition. According to others the contractions begin at the cardiac end and continue toward the pyloric end. This latter seems to be the more correct opinion. The movements begin at the cardiac end, which at first are quite feeble caused, by the contraction of the circular fibers, the wave thus originated passing towards the pyloric end with increasing force. When the wave reaches the parietal region it comes to a stop. Following this there is a contraction of the entire pyloric end which drives the liquid part of the contents through the fundus, an anti-peristaltic wave, being originated that returns the larger solid elements to the stomach again. There are thus two characteristic forms of movements. (1) The weak peristalsis of the fundus, pushing the contents toward the antrum and (2d,) the strong contraction of the sphincter pylori, accompanied by a strong stimulation of the entire antrum, both circular and longitudinal. These combined phases of movements would keep up a constant motion of the contents of the stomach toward the pyloric end. From this it will be seen that the fundic portion of the stomach is largely a reservoir for holding the contents, while the pylorus is the part of the stomach that through its muscles produces the stomach movements. The two parts of the stomach, therefore, have different and independent functions. This is of great advantage to the digestive process, as the large cavity represented by the fundus can hold the food, while gradually the food subjected to digestion, is sent down to the intestine through the pylorus. It not only assists digestion but protects the intestines from congestion so that the digestive process is completed.

VOMITING. This is intimately connected with these digestive movements that we have just explained, and hence, may conveniently be discussed in this part of Physiology. The act of vomiting is due to the direct or indirect stimulation of the center situated in the medulla. It may be produced, 1st. By the stimulation of afferent nerves of the gastric mucous membrane. For example, the introduction into the stomach of some irritant such as mustard, sulphate of copper, bile and undigested food. These substances either act directly upon the mucosa of the stomach or after absorption into the blood by influencing the reflex centers connected with the stomach movements. 2d. By substances introduced into the blood and acting upon it or else absorbed into the blood through the skin. For example, the injection of tarter emetic into the blood. 3d. Irritations of other organs affecting the stomach reflexly through the centers of reflex action. For example, tumors in the abdomen, certain conditions of pregnancy, gall stones, calculi, etc. 4th. Impressions reaching this center from the higher centers depending upon the psychic action, for example, arising from feelings, emotions, tastes, odors, etc. Sea sickness falls under this head, arising not from the food in the stomach but from a disturbance of the feeling of equilibrium in the bodily system, particularly in the stomach. 5th. Vomiting may arise from the reflex action produced by inflammations. For example, in acute meningitis. From the center in the medulla when it is stimulated a series of complicated efferent impulses pass. Some of these travel along the vagi aad cause contraction of the walls of the stomach and the abdominal muscles. There are several characteristic stages of vomiting in the conscious individual.

1st. Nausea. Vomiting is usually preceded by a nauseous feeling accompanied by a salival flow and the swallowing of some air which assists in the opening of the cardiac orifice to prepare for the discharge of the contents. 2d. Accompanying this is a deep inspiration by which the diaphragm is pushed down, the lungs being full of air, the diaphragm forming, thus, a solid base against which the stomach can be compressed. Accompanying this there is a contraction of the lower ribs, and the air does not enter the lungs as the glottis is closed, some air passing into the pharynx and to the stomach. Sometimes this compression causes the ejection of a quantity of gas. Associated with this is sometimes a retching accompanied with a deep inspiration. 3d. Immediately thereafter the fibers of the oesophagus contract longitudinally and are shortened, the opening of the cardiac orifice which is close under the diaphragm then takes place, in connection with the inhibition of the sphincter and the constriction of those fibers ranging from the oesophagus to the stomach. (4) The abdominal muscles and the gastric walls contract, the contents of the stomach being forced into the oesophagus along which they are carried into the pharynx by anti-peristaltic action and ejected through the mouth, the openings into the larynx and the nasal cavity being closed as in deglutition, although sometimes they remain open and matters are forced out through the nasal opening. When vomiting becomes violent the stomach is violently pressed against the diaphragm and the vertebrae, the abdominal muscles contracting powerfully, following this vomiting there is a deep expiration resulting in abdominal contraction, all the strength of the muscles being exhausted in the expulsion of the contents of the stomach. The involves a compression from the outside of the stomach. There are two marked actions in vomiting: 1st, the distension of the cardiac opening and 2d, the compression of the walls of the abdomen, both of these being necessary in order that the action may be affected. Sometimes the former takes place as poisoning by curare, in which case there is simply an internal stomach pressure, resulting in the emission of the gas. What is commonly called water-brash or heart-burn is probably due to this internal movement of the abdomen. Eructation of wind consists of a sudden forcing of gas out of the stomach producing a sound which is very characteristic in the upper part of the oesophagus. During vomiting the pyloric orifice is closed so that the contents do not pass into the duodenum. If the gall bladder is well filled there is a flow of bile to the duodenum along with the vomiting. In some cases this bile passes to the stomach, as in the case of bilious vomiting. The nervous arrangements of vomiting are obscure. The center is in the medulla in connection with the deep origin of the glosso-pharyngeal and pneumogastric nerves. There is really no special center. The reflex, however, takes place in connection with the medulla. But the respiratory muscles are those engaged in the act of vomiting. Vomiting consists of spasmodic actions of the expiratory and the inspiratory muscles. Some have concluded that the center is the same as that of respiration. This however lacks confirmation. In addition to this there is evidence that if the medulla is divided so as to suspend vomiting, respiration continues. Efferent impulses causing the deep expiration must come from the respiratory center. The distension of the cardiac opening is produced by stimulation passing along the pneumogastrics, because if these are divided vomiting is prevented or rendered almost impossible through lack of dilatation of the orifice. The internal stomachic movements and the movements of the oesophagus are carried out under the influence of the glosso-pharyngeal and the sympathetic nerves. The salival flow in connection with the nausea arises from impulses passing along the chorda tympani. These various mechanisms are brought into activity by the stimulation of different centers, impulses being passed from one center to another, thus interfering with the rhythm of the movements in the stomach. Vomiting is, therefore, a reflex action, the impulses usually passing along the splanchnic and pneumogastric nerves. This does not prevent direct action upon the centers as in abnormal conditions of the medulla resulting in cerebral vomiting and in some cases of poisoning as

well as under the influences arising from the higher centers that depend upon emotions. Irritations in vomiting may give rise to stomach movements, the movements of the abdominal muscles and the respiratory movements. Those interferences with normal movements take place by the radiation of impulses from center to center. Vomiting is thus a reflex action resulting either from sensory stimulation or from injury to the nervous system. Injuries of the brain cause cerebral vomiting. The most regular cause, however, is the stimulation of the mucous membrane of the stomach the afferent path being along the pneumogastric and the efferent path being found in the motor fibers of the vagus, phrenics and spinal nerves.

SECTION VIII. (2) The Gastric Juice.

When food reaches the stomach it is brought into contact with the gastric secretion which begins as soon as the food enters the stomach, The gastric juice is easily obtainable for experimental purposes but it is difficult to determine the normal characteristics of the fluid in the stomach. By causing an animal to swallow a sponge the sponge can be withdrawn and the juice squeezed out. In the famous case of St. Martin, who by a shot was wounded in the abdomen, there was a fistulous opening existing in the abdomen wall and the stomach wall so that the contents of the stomach could be easily examined. The most easy method is by means of the gastric fistula through the abdominal walls introduced into the stomach. Investigations have been made in connection with the production of artificial gastric juice secured by the use of alcohol in connection with the mucous membrane of the stomach, afterwards using glycerine and hydrochloric acid. These, however, only represent in a general way the gastric juice as normally it is complicated by mixture with the food, fluids, etc. When it is secured in purity it is a thin, clear, colorless fluid with a sour odor and taste, the reaction being distinctly acid, arising from free hydrochloric acid to the extent of about 1-10 to 2-10 per cent. Its specific gravity in the human subject is about 1.001 to 1.003. On microscopic examination it does not present any well marked characteristics. In the human gastric juice the amount of solid matter is very small, about .5. Of this solid matter the greater proportion is found to be salts, especially the chlorides about .2 per cent, and small quantities of phosphates with small traces of iron. There is always a free acid, hydrochloric acid, together with lactic acid and other acids which are secondary, the result of fermentation changes in the food. There is a small quantity of albumin, some mucin and a ferment pepsin which can be extracted from the gastric mucous membrane by glycerine and which when dried appears as a grayish white powder, slightly soluble in water. This pepsin in combination with hydrochloric acid has the power of converting ordinary proteid substances into peptones which differ from the ordinary proteid snbstances as follows:

1st. Their solutions are not coagulated by heat or by alcohol. When boiled no coagulation takes place but the digestive character is destroyed. 2d. They have the power of passing with considerable ease through animal membranes. 3d. They are easily dissolved in water. 4th. Mineral acids, acetic acid and such other acids do not precipitate the solution. 5th. Such acids as tannic acid, corrosive sublimate, do cause precipitation. 6th. In cold they yield a purple red color when added to an alkaline solution of hydrated capric acid. 7th. In dry powder dried at 105° C it is of a bright yellow color, the powder freely absorbing water from the air. Besides pepsin the gastric juice contains another ferment which, as it has the power of curdling milk, is called the renin ferment changing milk sugar into lactic acid. The gastric juice freely dissolves coagulated proteids which seem to be almost insoluble. There are supposed to be several kinds of peptones in connection with the gastric juice. These all differ from albumose in the fact that peptone is diffusable, whereas, albumose is not, and a peptone cannot be precipitated by sulphate ammonium like albumose. The gastric juice changes the less soluble proteid into a soluble form being either converted into peptone which is the most soluble form of the proteids or else being left in the less soluble form of para-peptone. Gastric juice resists putrefaction even after being kept for months. It does not become putrid and it does not lose its digestive or acid character. This makes the juice antiseptic. This conversion of proteids into the peptones is facilitated. 1st. By a medium temperature from 35 to 40°C. 2d. By certain mevements such as we find in connection with the stomach's constant movements, favoring digestion. The presence of acid below or beyond the normal percentage, .2 per cent of hydrochloric acid, retards the action of the juice; the making of the juice alkaline and a temperature below 50°C or above 60°C and the presence of concentrated digestive product retards, or arrest the changes in connection with gastric juice. The blood is conveyed to the fundus and the pyloric glands the fluid being poured from the capillaries so as to suffuse the membrane, the plasmic fluid being secreted in the cells of the glands as the elements out of which the juice is formed. In the glands of the plyorus the pepsin is formed. When the stomach is inactive, the marginal glandular cells decrease in number. When food is introduced into the stomach the principal cells decrease, producing large numbers of marginal cells in which the hydrochloric acid is formed, whereas the pepsin if found secreted in the principal cells in connection with the fundus and pyloric glands.

Heidenhain separated a part of the fundus in the dog from the rest of the stomach without interfering with the vascular connections. This part of the fundus he formed into a sac by stitching; he formed in the same way a pyloric sac. The fundic sac secreted the fluid containing pepsin and hydrocloric acid, while the pyloric sac contained a viscous alkaline secretion containing pepsin. He concluded that as marginal cells are found only in the fundus they secrete hydrochloric acid and as the principal cells are found both in the fundus and the pylorus he concluded that they secreted pepsin. The hydrochloric acid is formed out of the blood. It is difficult how to explain how the alkaline blood produces free hydrocloric acid. It is supposed that lactic acid is first formed by means of the ferment, the acid setting free chlorine from the sodium chloride, the chlorine being combined with the hydrogen to form hydrochloric acid. CO_2 is the only acid in the blood and it is said that chlorides are decomposed by its action. This, however, is impossible. Others suppose it due to certain currents passing through the mucous membrane producing reaction in the carbonate of sodium and the sodium chloride of the blood. At one time it was supposed to be due to the lactic acid alone.

Schmidt then showed that if the chlorides were precipitated by silver nitrate more chlorine would be found than could be held in combination with the gastric bases. The lactic acid, however, may and often does exist in the juices. The lactic acid is explained as arising from fermentation of the carbohydrates. The gastric juice is the only secretion containing a free acid. Various attempts have been made by injecting coloring reactions into the blood to locate the secretion of the acid, but so far without success

unless to the extent of proving that the acid is formed in the mucous membrane. As no free acid exists in the blood it must be formed in connection with the cells. It is supposed by some that the hydrochloric acid is held in combination with some of the proteids of the secretion, the result being that the acid is not so easily distilled or dyalized as in its free condition. In proof of this it is stated that the para-peptones and the peptones very freely combine with the acid. A more probable explanation is that it arises in the molecular dissolution and of the chlorides accomplished by the protoplasmic action of CO_2. The liberated base in this case is excreted by means of the kidneys, the urine acidity being inversely in proportion to that of the stomach. In the principal cells there is found certain matter which, under the influence of hydrochloric acid produces pepsin, the albumen being converted into peptones. Thus the matter inside the cells contains substances which can produce pepsin, and hence this internal substance is called pepsinogen. This pepsinogen is supposed to be in union with a proteid and it is supposed that the union is broken up by the use of acid. If both pepsin and pepsinogen are found in the same fluid, a one per cent solution of sodium carbonate will destroy more pepsin than pepsinogen and CO_2 will destroy more pepsinogen than pepsin. If all the pepsin is removed from the stomach by a glycerin solution then more pepsin can be obtained by the hydrochloric acid or sodium chloride solutions.

The pepsin found in the gastric juice varies according to the stages of the digestive process, being smallest about the second hour and greatest about the fifth hour, after which it falls to about the normal. There is no pepsin found in the mucus of the foetal stomach during foetal life, although it is said that just before birth the stomach assumes the digestive powers. The gastric juice in digestion seems to act as a ferment, this ferment being the pepsin. It is not inself a proteid; it differs from ptyalin, the salival ferment in this, that pepsin has a close affinity for acid, whereas, ptyalin is most active in a neutral solution. In the case of pepsin united with hydrochloric acid we have a compound pepto-hydrochloric. Pepsin is a proteolytic enzyme which acts only in an acid fluid. Hence, the digestion in the stomach is the result of the union of pepsin and hydrochloric acid. A low temperature hinders its action and may arrest its activity; the higher temperature increases its action. The normal temperature is about 35° to 40°C. If the temperature is raised to 70° or 80°C it destroys the pepsin. The amount of pepsin in the gastric fluid varies from .2 to 1.5 per cent. Pepsin is freely given up to glycerine. If the mucous membrane of the stomach is divided into small pieces and steeped in alcohol for a day, then removed from the alcohol and put into a strong glycerine solution in which it is allowed to remain from 10 to 21 days, after which the fluid is strained, this gives us the glycerine extract of the mucous membrane which is found to be very peptic. It may also be obtained by pouring a 5 per cent solution of phosphoric acid and later some lime water on the mucous membrane. Phosphate of lime precipitates pepsin. If the precipitation is collected and washed with water then dissolved in a .5 per cent hydrochloric acid solution, a solution of cholesterin, alcohol and ether produces a precipitate of cholesterin and pepsin. By the use of ether the cholesterin is dissolved and there is left a fluid solution of pepsin. The gastric juice on analysis yields in 1,000 parts, according to Schmidt 994.4 parts of water; 3.19 of pepsin and other organic matter; 1.46 sodium chloride; .55 potassium chloride; .06 calcium chloride; .2 acid and .12 phosphate of lime, magnesia and iron. Artificial digestion may be carried on at a temperature of 35° or 40°C. Below this the process becomes slow and at 4°C it is arrested. In addition to the pepsin there is usually present the rennin ferment and the lactic acid ferment which converts sugar into lactic acid. Syntonin is formed during the first part of the process. By the use of an alkali this may be precipitated, a part of the proteid substance being left in the neutral fluid, this substance being peptone. In addition to this there is formed the parapeptone, an albuminous substance soluble in water and may be precipitated by nitric acid. If heat is applied to the precipitate it dissolves but it may be precipitated again by cold. In the first stage of the digestive process a large proportion of the para-peptone or pro-peptone is found and a small quantity of peptone. As the digestive process goes on, the peptone increases and the para-peptone decreases until at the close of the digestive process very small traces of the para-peptones are left with a large quantity of peptone. In the process of digestion a number of intermediate substances are formed, called by Halliburton, proteoses, these different substances representing the different stages in the development of peptones, all of them being albumose in character. All these albumoses are precipitated by ammonium sulphate. Kuhne says that the proteids divide up into anti-peptone and hemi-peptone bodies; the anti-peptone being divided later under the action of tripsin in the pancreatic juice into leucin and tryosin. To discover the presence of pepsin in a fluid, acetic acid must be first added, then the substances must be saturated with ammonium sulphate and then filtered. This is then treated with strong hydroxide and a very small quantity of cupric sulphate dilution. There will be a red colored reaction if there is peptone present and a blue colored reaction if there is no peptone present. When the proteid is acted on, according to Kuhne it is converted into the syntonin which is the characteristic peptone of the acid albumin. If the liquid if neutralized syntonin will be formed chiefly due to the presence of hydrochloric acid. The syntonin is then hydrated under the pepsin influence the dissolution forming the proteoses, proto- and heteso proteoses. Each of these substances changes again under the influence of hydration, forming secondary protoeses, these secondary proteoses being again changed in the formation of peptones. Here the digestive action of the gastric juice ceases, although the peptones may be still farther changed under the influence of the tripsin ferment. All of the stages after the development of syntonin are hydrolytic stages according to which dissolution takes place of the proteids into smaller bodies, these representing the proteoses and peptones. Formerly all the products of digestion following the syntonin were called peptones, but now, under the influence of Kuhne's experiments the peptones are taken to represent the final products of the digestive action, the test of the peptone being the absence of precipitation under the influence of ammonium sulphate. The peptones are albuminous. It is supposed that they are formed by hydration an atom of albumin being united with a drop of water. This is proved by introducing acetic acid into the pepsin and thus dehydrating the molecules by removing the water and thus converting the peptones into the albumin. By the action of a .4 per cent solution of hydrochloric acid at a temperature of from 40° to 60°C peptones may be produced. If albuminous substances are boiled for a long time peptones will also be formed. This production of peptone is slow, whereas, by the action of pepsin the formation of peptone is rapid. The hydrochloric acid may be replaced by lactic acid, phosphoric acid, oxalic acid and succinic acid. The digestive process is influenced, first by gastric secretion which goes on during the entire digestive process, the food being

mixed with fluid in connection with the pepsin and hydrochloric acid so as to produce the proper mixture and dilution of the food. 2d. When the peptones are formed during digestion they are absorbed into the blood through the blood vessels together with water, the remnants being passed into the small intestine. 3d. The stomach movements facilitate digestion by introducing the food contents into the different parts of the mucous membrane of the stomach and thus bringing them into contact with the gastric juice. 4th. Albumin will be readily transformed into peptone at 40°C, being stopped below 5° and above 60°C. 5th. The pepsin is quickly destroyed by the action of alkalies, its action is also hindered by the metallic salts, sulphurous and arsenious acids, large quantities of cold water and the presence of a large quantity of the peptone itself. A small quantity of salt favors the process of peptone formation. When the stomach is empty its mucous membrane is of a pale greyish color and covered with a thin layer of mucous. The introduction of any substance, more especially food, leads very promptly to the dilatation of the blood vessels of the mucous membrane, which consequently becomes red in color and also leads to the copions secretion of the gastric juice. The gastric secretion may be produced by the feelings or emotions through connection with the higher centers in the brain. The dilatation of the blood vessels and the consequent secretion of the gastric juice is a reflex action similar to that which produces the flow of saliva.

If the vagi are divided during the digestive process the mucous coat becomes pale and stimulation applied to the central end of the divided nerve produces the dilatation of the vessels in the membrane. Afferent impulses, therefore pass from the gastric mucous membrane along the vagi to a center in the medulla, inhibiting the action of the vaso-motor center governing that region, resulting in diminished nervous impulses to the stomach blood vessels, producing dilatation. Efferent impulses pass along the fibers of the sympathetic to the ganglia in the walls of the stomach. These ganglia exert a local influence upon the calibre of the blood vessels and perhaps also the activity of the corpuscles in the gastric juice. Sensory impulses may also arise in connection with the mucous lining of the mouth by the stimulation of food. Thus any substances or acid in the mouth produces gastric secretion. Local centers seem to exist in the stomach, influencing the blood vessels and the secretion. By the general influences of temperature, the stomach movements and the direct action of the gastric juice, the food contents become so changed as to be prepared for absorption. The result of these influences on the food is to form a semi-fluid, heterogeneous mass, the chyme. This has an acid reaction with an acid odor and differs in color according to the character of the food. It consists of water, salts and sugar converted out of starch by the salival action, the remnants of starch left over from the salival process, fatty substances which have been dissociated from the food or liberated from the animal cells, albumin in the various stages of development into the peptones and the undigested and the indigestible matters left over after the action of the digestive juice. There are two stages, thus, in the digestive process in connection with the gastric juice. 1st. A short period during which the saliva acts upon the starch found in the stomach in fermentation, and 2d. A longer period during which the peptones are developed under the action of gastric juice. The first stage depends upon the acidity of the juice; if the juice becomes acid to the extent of .5 per cent then the salival fermentation ceases, this acidity of the gastric juice retarding butyric fermentation, and lessening the amount of hydrogen in the stomach. There is found in the stomach, always certain quantities of gas, either from the air taken in with the food or the air generated in the inrestinal organs. The O from the air taken in by the deglutition becomes quickly absorbed so that in the stomach the gas is deficient in O and rich in CO_2. The gastric juice acts differently upon the different food substances. Milk becomes rapidly coagulated, the saccharine and salt substances found in solution being absorbed, the fatty substances being freed from the milk cells and the casein changed into peptone. The coagulation of milk is produced by the rennin ferment, this ferment being easily destroyed by alkaline solutions. Milk may be coagulated by the addition of gastric juice. If the gastric juice is raised to 60° C or above, no coagulation takes place. The rennin is very powerful, one part coagulating 800,000 parts of milk. The milk curdles by the contact with the mucous membrane. When a calf's stomach is dried and a rennet is produced, it coagulates milk very rapidly. This is due to the existence of an enzyme rennin zymogen which exists in all normal stomachs. The rennin acts upon milk proteids or casein, changing it from a soluble to an insoluble curd. There must be present lime salts. Casein is a nucleo-albumin which under the influence of the rennin becomes hydrated and is divided into two simpler bodies, para-casein and whey. The para-casein with the lime salts form the curd or clot. The casein may also be curdled by excessive acid.

If the milk stands for a length of time, lactic acid is formed under the bacterial action upon the sugar, producing casein in the coagulated form. The rennin ferment does not act upon any other substance but the milk. It is important in connection with the milk because of the nutritive value of casein. After the casein has been coagulated it is acted upon by pepsin in the formation of proteoses and peptones. Gelatin is acted upon by pepsin just as in the case of albumin. In the formation of the products of gastric digestion in connection with the pepsin there are formed gelatoses and gelatin peptones. When the gelatose condition is reached the pepsin is said to yield to the tripsin of the intestinal juice which completes the peptone formation. The gastric juice does not act directly upon the carbo-hydrates; hence, it does not act upon starch There is, however a partial digestion of the carbohydrates of the stomach as the carbohydrate food is thoroughly insalivated but it is subject to ptyalin action before the acidity of the stomach becomes complete. This however, is insufficient, as the acidity becomes so great as to destroy the ptyalin. Gastric juice does not act upon dextrose. It has been stated that cane sugar is subject to the action of the invertin ferment in the stomach, being transformed into dextrin and laevulos, a process that is completed in the intestinal digestion. In a stomach that is unhealthy, where much mucus exists there is a free conversion of cane sugar to dextrose. The gastric juice has no direct action upon the fats. There is no splitting or emulsification of the fats in the stomach. The fats, however, are brought under the influence of a higher temperature that is sufficient to melt them, so that in liquid form they become mixed with the solid food and ready for easy digestion in the intestines. In the case of proteids we have the chief action of the gastric juice. Among these are fibrin, insoluble in water, which becomes swollen and dissolved under the gastric juice, forming a clear fluid which is changed into peptone. Coagulated albumin insoluble in water becomes swollen and gradually breaks up, being reduced to a soft mass which becomes peptone. Acid albumin, including syntonin, insoluble in water and soluble in dilute

acids and alkalies becomes converted into peptones. Coagulated proteids present the change under the influence of temperature, being insoluble except in strong acids. Egg albumin coagulates at 75° C. The gastric juice very rapidly absorbs these coagulated proteids even when insoluble by fluids.

In the case of animal muscles a dissolution takes place in the connective tissue between the fibers, exposing the transverse striæ. In this way the fibers are broken into pieces and thus dissolved into their elementary substances. The ligamentous, tendinous and cartilaginous tissues dissolve more slowly, particularly if raw. After being cooked they are acted upon very much like gelatine. The gastric juice does not affect the corny tissues, such as hair, nails and skin. The elastic tissues may be dissolved under lengthened digestion yielding up an elastin peptone. The red corpuscles become disintegrated, the hæmoglobin being separated into haematin and globulin under the influence of the gastric juice, the globulin being transformed into peptone. Bones are not dissolved but the acid of the gastric juice extracts some of the salts leaving the bone in a honey-combed condition. Vegetables in their natural condition are indigestible because of the enclosure of the substances with in a cellulose covering, the cellulose being unchanged by the gastric juice. After being cooked the cellulose yields, liberating nutritive elements such as starch, sugar, etc., setting them free to the action of the gastric juice. Some of the salts are dissolved in the juice, such as phosphates of lime and carbonates, this dissolution yielding CO_2 in the case of the carbonates. Bone when broken up yields the salts, the organic substances yielding gelatin peptones. Experiments have been made to test the rapidity of the digestive process. In artificial digestion the process is much slower than it is normally in the stomach. The rate of digestive action depends upon the food, its nature and also upon the division that takes place in the food, so that if the division is increased so as to increase the superficial area of the food with which the juice comes into contact the process is assisted. Fluids are quickly absorbed, the solids contained in the fluids being concentrated before coming into contact with the gastric juice. The solid substances of food are normally very quickly subjected to digestion. It is estimated that within 30 minutes after a meal is taken the food is changed into chyme, the stomach being emptied within two or three hours. Various experiments have been made in the attempt to discover foods easily digested.

Beaumont found that tripe and rice digest in one hour; eggs, apples, trout, fish, salmon and venison in 1½ hours; milk, barley, liver, fish and tapioca in 2 hours; lamb, pork and turkey in 2½ hours; mutton, fowl and beef in 3½ hours and veal in 4 hours. This does not indicate the nutritive value of the foods, because rapid digestion does not always indicate that the food is nutritious. In the case of a dog fed upon animal food it has been found that digestion begins immediately, continues active during the first two hours then gradually diminishes in activity until the 12th hour, when the digestive action is completed. When the food passes to the stomach there is a flow of gastric juice, the flow beginning even before the food reaches the stomach, the stomachic movements increasing the flow. As digestion progresses, the acidity increases also. By the action of the gastric juice, there is a breaking up of the food so as to form the soluble chyme. This acid chyme consists of dissolved proteids, proteid particles, fatty particles and small lumps of food substances. When the chyme is filtered so as to remove the solids from the fluid it is found to contain salts, pepsin, hydrochloric acid, sugar peptones and para-peptones, the last three varying in quantity. As digestion proceeds the chyme is ejected through the pyloric orifice into the duodenum, the length of time elapsing before this takes place depending upon the nature of the food, whether solid or liquid, and also upon the nature of the solid food. The normal passage from the stomach to the duodenum in the human subject taking place from 1 to 5 hours after the food is taken, great variation being found in the nature of the change taking place and the length of time necessary for such a change. Some of the peptone formed becomes absorbed without passing into the intestines. In the passage of the food to the stomach considerable quantities of air pass into the stomach. Part of this is driven out in the form of gas, this gas consisting mainly of nitrogen and CO_2, the O being absorbed in the stomach. Some of the CO_2 is diffused from the blood and some arises from the fermentation changes taking place in the stomach and in the intestines.

SECTION IX. Modifications of Digestion.

The question is asked in Physiology; "why does the stomach not digest itself?" The stomach of another animal will be readily digested. If the animal is killed, the stomach, itself, may be subjected, at least partially, to digestion, if the normal body heat is kept up. Even in the living subject if the circulation is cut off from a portion of the stomach, as in the case of intra-vascular blood clotting, or ligaturing the blood vessels, the gastric juice will attack thc stomach itself, resulting sometimes in perforation of the stomach. The stomach of another animal is freely digested in the stomach under the influence of the gastric juice. Some have suggested that the vital principle protects all the living organs, such as the stomach and the small intestines, from the action of their own secretion. This does not explain, however, the protection, for it has been shown that the leg of a living frog may be introduced into the stomach through a fistula without severing its connection with the living body, in which case the digestive process will go on. The vital principle is such an indefinite quantity that this is really no explanation of the fact of the immunity of the stomach from its own secretion. Others have suggested that the epithelial lining of the stomach protects it, or that the blood, which is alkaline in its nature, by freely circulating in the organ, neutralizes the acidity of the juice, preventing the digestion of the stomach. The stoppage of the blood withdraws this element and permits of the action of the secretion upon the stomach. In cases where death is sudden, post-mortem examination gives evidence of the partial digestive action in the corrosion of a portion of the lining of the stomach. This corrosion extending even to the proximate organs, such as the diaphragm and the liver. This view does not explain the protection afforded to the intestines against the action of the pancreatic juice. The immunity probably arises from the living properties of the organ, the stomach and intestines, the organs being arranged so structually as to be capable of resisting in normal conditions, the digestive action of its own secretion.

What are the conditions that favor digestion? Aside from individual characteristics which play an important part in the digestion of food, digestion depends upon a number of circumstances which affect the gastric juice: 1st, the amount of food taken and the nature of the food. In order to promote digestion the stomach needs to be normally dilated. This, of course, implies a moderate supply of food. 2d. Sufficient time should elapse between meals so as to permit the food to be completely digested

before new food is introduced into the stomach. 3d. Sufficient exercise both before and after eating assists digestion. This means moderate exercise, because violent exercise is dangerous and against digestion. 4th. The psychic conditions also influence digestion. Disturbed conditions interfere considerably with digestion. Mental equilibrium, therefore, is a favorable condition. 5th. The physical health of the body is also a necessary condition of proper digestion. 6th. Age and the changes in life affect digestion. Digestion is more active in the young than in the old, the changes of life, whether in regard to changes of avocation, temperature, or the normal changes in life influence digestion. The stomach's function normally is to act upon the food by chemical and physical processes, so as to prepare the food for later digestive stages in the intestines. The stomach first concentrates the food substance into a semi-fluid substance representing partially digested as well as the undigested food matters, to be more completely digested in the intestines, called the chyme.

Gastric digestion is largely preparatory, therefore to pancreatic digestion under the influence of the trypsin ferment. The transformation in the stomach does not pass beyond the proteose condition to any great extent, as the peptic digestion is largely preparatory for the triptic digestion, in the intestine, the trypsin being much powerful than the pepsin. According to this, a human being can live without a stomach. We have to give up the idea of the stomach as a vital organ, as the stomach has been entirely removed, the oesophagus being united with the small intestine. Dr. Schlatter of the University of Zurich recently removed a woman's stomach, joining together the approaches to the stomach from the two sides. He reports his patient well, and able to enjoy health without any stomach. Some think that this is not a proof of the ability to live without the stomach normally, as the stomach in this case was so impaired as to be useless in any case. It gives evidence, however, of the extension of the principle of functional sympathy to the stomach.

The digestive process is modified in some animals. In the stomach of the pig we find two parts, one part on the left side continuing the oesophagus, and the other part on the right side forming the stomach proper. In the former part there is a finer mucous lining much less moist with no glands but covered over with small papillary eminences. In the other part the mucous lining is very thick, containing glands very much like the fundus glands.

In the horse the stomach is very small compared with the amount of food that is used. The right portion is the true stomach, the left portion being the oesophagal part covered with a layer of mucous membrane, very white in color. The pyloric orifice is much less tightly closed than in the human subject permitting the free passage of the food substance into the small intestine. In the ruminating animals, the stomach is much more complex. There are four parts or sacs. 1st, the rumen, 2d, the reticulum, 3d, the omasum, 4th, the true stomach. The rumen is a very large sac covered with mucous containing very large conical papillary eminences. This is connected with the lower end of the oesophagus and also with the reticulum, being divided from the latter by a strong band of fibers, from the omasum and the true stomach, similar to those found in the human subject in connection with the cardiac part of the stomach. The reticulum is in the form of a net-work consisting of a large number of cells, the muscular coat being very strong, and its fibers being continuous with the oesophagus. There are three orifices in the reticulum; one into the rumen, another one into the omasum, and another to the oesophagus. The omasum has a fine wall with two openings into the reticulum and the true stomach. The mucous lining consists of leaves or flaps folding over into the sac, these being covered round papillæ. The true stomach is like the stomach in other animals with the fundus and plyoric glands. The food when roughly broken up and forming boli passes down the œsophagus into the rumen. Fluids may pass immediately into the omasum ; if the amount of fluid is excessive, a part may pass to the reticulum, the free watery fluids thus passing to the reticulum while the more viscous fluids adhere to the œsophagus opening or enter into the omasum. The fluid is mixed with saliva passing into the rumen where the food is moved about and broken up and softened, fermentation taking place. After the complete mixing rumination begins. The action is almost identical with vomiting. The ruminal muscular walls contract, the reticulum and diaphragm also contract with the muscles of the abdomen, resulting in the driving of the food into the mouth, the nasal openings being closed. The food now becomes masticated and insalivated, afterward repassing down the œsophagus, passing into the omasum, the more fluid matters passing almost directly into the true stomach, while the rougher elements are passed through a process of filtration among the folds of the omasum. The fluid that is extracted passes into the true stomach, and the solid matters are also driven into the true stomach by the force of the contraction of the walls. In the true stomach digestion proceeds as in the human stomach.

SECTION X.—Digestive Processes in the Small Intestine.

The chyme formed in the stomach is carried through the pyloric opening into the small intestine by peristaltic action. These peristaltic movements take place from above downward, the undulation beginning at the pylorus and extending down, although there are contractions originating all along the intestine. These peristaltic movements take place successively with intervening periods of rest. These movements secure the slow passage of the chyme along the small intestine and its mixture with the three juices, the bile, the pancreatic and the intestinal juices which act together upon the food. There is also a process of absorption taking place in the intestines, the water, fatty and soluble matters being given up in the passage through the intestine. The muscles of the small intestine are arranged in two layers, an inner circular and an outer longitudinal between which and the submucous coating are the nervous plexuses. The muscular arrangement is the same as the stomach and therefore the peristalsis is similar. The small intestinal movements consist of regular and successive peristaltic contractions from above downward, the calibre of the intestine being lessened. There is also a contraction longitudinally in the tube so that lengthwise it becomes shorter. When the contractions become violent longitudinally, then the contraction takes place by loops. These contractions are due to the contraction of the circular fibers and the longitudinal fibers respectively, both acting simultaneously producing writhing movements. These represent the peristalsis moving about 10 to 12 mm. per second and the pendular movements. The peristalsis consists of the contraction of the intestinal walls beginning at the upper part and extending downward section by section, the portions behind relaxing. This pushes forward, the contents of the intestine. The contraction takes place chiefly, if not altogether in the circular layer. Anti-peristalsis consists of a movement in the opposite direction away from the intestine toward the stomach and generally occurs in abnormal conditions. It has been reported that certain substances introduced into the rectum move upward by such a kind of movement. That the normal movements is from above downward has been shown clearly by some experiments in which, after dividing the intestine, it has been sutured with the lower end upwards. In cases in which death has taken place, there has been found a great accumulation of matter at the upper end, indicating the reverse of the movement. By opening the abdomen the peristaltic movements have been observed running rapidly along the intestines. This, however, is somewhat abnormal, due to the stimulation of the air as the normal peristalsis is slow and gradual. It has been estimated that during rest it goes at the rate of one centimeter per two minutes. During digestion, and especially during exercise the movement is very much more rapid, about one centimeter in 20 seconds. A question has arisen as to the origin of the peristalsis. At each contraction of the antuml plyori the chyme is ejected in to the duodenum originating at the same time the peristalsis that moves slowly along the walls. The passage takes place probably by progression from cell to cell in the circular coating, the distribution being due to the conduction from layer to layer. This is not sufficient to explain the action as the anti-peristalsis would require an explanation. Possibly this muscular action is aided by the nervous impulses passing from the local ganglia. Besides peristalsis, we find pendularicity. This is named from the fact that has been observed that on exposing the intestines there is an oscillating movement of the intestines. These are supposed to be due to the rhythmic contractions of the longitudinal muscles. These movements are supposed to be chiefly of value in maintaining the normal circulation of the blood in connection with the intestines and in preserving the blood pressure in the portal veins. The peristalsis usually originates at the pyloric orifice. It may also originate along the course of the intestines always moving downward. In the intestinal coats there are two nervous plexuses, the one in the connective tissue of the submucous layer and the one lying between the two muscular layers. There are also visceral fibers from the pneumogastrics and the splanchnic sympathetics. By the severance of the intestine from nervous connection with the central nervous system and stimulation of the intestine the peristaltic action may be produced indicating that the ganglia within the intestine act as independent centers in producing these movements. The vagi on stimulation produce intestinal movements and are therefore said to be motor fibers. There may be, however, inhibitory fibers, although the motor fibers seem to prevail. These movements depend not only upon nervous stimulation but also upon the condition and amount of the blood supply and the peristalsis may be excited by mechanical or electrical stimulation. The peristaltic action is increased by anaemic and also by plethoric conditions of the blood. In both cases there is an excess of CO_2 and a deficiency of O, the gas acting as a stimulant.

When the circulation is partly suspended or when severe hemorrhage withdraws a large quantity of the blood, the movement is increased. During the digestive process, there is an extra blood supply, this acting as a stimulant upon the action. If the stimulation is increased to excess paralysis ensues, and the action is suspended. An excessive blood flow amounting to conjestion and inflammation have the same effect, the muscular walls becoming dilated when filled with gases. If the pneumogastrics are stimulated, the action is increased, whereas, the stimulation of the sympathetics stops the contraction, indicating that the pneumogastrics act as an accelarator of the centers in the intestinal walls, while the sympathetics inhibit the action of these centers. This inhibition depends upon the character of the blood. It is said that the sympathetics for the small intestine arise from the spinal cord from the 6th dorsal to the 1st lumbar, spinal nerves passing to the sympathetic chain through the splanchnics, then to the semilunar plexus. The large intestine is supplied from the 2nd to the 5th lumbar spinal nerves and through the sacral nerves, the nerves passing through the hypogastric plexus and producing contraction of the muscles. If the blood is normal as between arterial blood and venous blood inhibition takes place, but if the blood becomes venous inhibition is changed into acceleration. This seems to indicate the presence of two kinds of fibers, motor and inhibitory in the sympathetics, the inhibitory fibers being counteracted by the venosity of the blood. The higher psychic centers may also influence the peristaltic action as in cases of emotional conditions and nervous diseases, producing constipatory conditions. The stimulation aroused by strong emotions, originating in the brain, influences the vaso-motor center causing contraction of the vessels in the abdominal region, resulting in the anaemic condition of the blood, giving rise to strong peristaltic actions. The nerves regulate the intestinal movements from or through the central nervous system. Their pathway through the system is obscure, the connection, however, reaching the psychic centers. If the nerves are all divided so as to cut off the intestine from its nervous connection, the muscle contraction is not interfered with. Normal peristalsis seems to be independent of nerve control, although the regulation of blood will follow the nervous system. It seems therefore, that peristalsis normally in the intestines may be accomplished independently of the central nervous system, the nervous system being regulatory of its action much in the same way as all the other organs are regulated and controlled by extrinsic nervous connection. Such movements of the intestines may be stimulated by chemical action upon the intestinal walls, for example, potassium salts produce contraction where the potassium is applied. Sodium salts produce the same away from the point of application, spreading downward like normal peristalsis. If the blood supply is cut off and then suddenly allowed to return, strong peristaltic movements follow. Sometimes dyspnœa originates peristalsis, or quickens the rate of already originated peristalsis, acting through the central nervous system. O in the intestine arrests and CO_2, H_2S increase the peristaltic action, similarly acetic and formic acid, developed under the influence of bacterial growth produce stimulation of the peristalsis.

SECTION XI. *The Liver and Bile.*

The liver represents the largest of all the body glands weighing from 1.4 to 1.7 kilograms, representing about 1-35 of the weight of the entire body, although greater in fœtal and early life. The main portion of the gland consists of, first, the hepatic duct arising from the transverse liver fissure, joining with the cystic duct at the lower end as it comes from the gall bladder, uniting to form a common duct. 2d. The gall bladder consists of a conical shaped sac, the fundus being directed downward and forward extending beyond the anterior part of the liver and the lower end, giving rise to the cystic duct. 3d, The common bile duct is formed by the uniting of the cystic and hepatic ducts extending to the lower part of the duodenum, opening into the bowel by an opening common to it and the pancreatic duct. This opening is so arranged that there is no regurgitation of intestinal contents into the duct. The lobules of the liver get their blood supply from the portal vein which forms the main channel of the veins of the stomach, pancreas, spleen and intestine. All the blood passes through these entering the liver. The blood from the portal liver holds in solution soluble proteids and carbo-hydrates absorbed during alimentation and these are brought into contact with liver metabolism. The hepatic artery furnishes it with arterial blood from the general systemic circulation. The liver structure is peculiar, the one side of the gland cells being turned in the direction of the main gland cavity. The blood capillaries are closely connected with the hepatic cells, on several sides these blood capillaries never coming into close relation to the bile capillaries which carry off the bile secreted in the cells, or into relation with the ducts. The blood capillaries pass along the margins of the cells and the bile capillaries along the middle of the side. In this gland, therefore, the blood capillaries are very closely related to the secretory cells. These hepatic cells are of irregular shape, with angular edges. having no cell wall. While fasting the cells are small, during digestion they are larger. The lymphatic vessels accompany the branches of the portal vein, forming spiral plexuses around these. These lymphatics enter into the lobules around the blood capillaries and around the minute veins. The liver nerves arise in connection with the cœliac plexus, and from the pneumogastrics, chiefly the left one. They join the liver in close relation with the hepatic branches. They are found in connection with the local ganglia some of the nerve fibers ending in the hepatic cells. The lower is very important from the standpoint of alimentation, this action depending largely upon the character of the cells. Thus, there are two main questions for discussion in connection with the liver, the formation and character of the bile and the metabolism connected with the formation of urea and glycogen which we will discuss in connection with excretion and metabolism.

1. BILE In the liver we find a number of lobules, each lobule being supplied with blood from the portal and hepatic circulations. From the portal circulation there comes blood which has been circulated in the stomach and intestines bearing substances absorbed from those organs, while the hepatic cir culation conveys arterial blood from the nutriment of the organ itself, its tissues and its vessels. From the portal blood the lobular cells secrete substances which are given off into the duct for the formation of bile. This blood when robbed of these matters returns through the heptic vein to the heart. The portal blood entering the liver contains a larger amount of albumin, hæmoglobin, fat, salts and water and less cholesterin and lecithin than that returned to the heart. The portal blood brought to the liver also contains saccharine matter taken from the carbohydrates, while the blood returned to the heart contains sugar from glycogen. The lobular cells, therefore, are the seat of bile secretion and also of glycogenesis, urea formation, etc. The substance of fresh liver is alkaline in reaction, becoming acid after death. In it we find various proteids. The hepatic cells also yield 1 to 1½ per cent of glycogen, fatty matters, urea, uric acid, cholesterin, jecorin together with organic salts, potassium, sodium calcium or magnesium and iron together with such metallic substances as copper, mercury lead, etc., extracted from the food. The bile is both a digestive secretion and an excretion, the former being used in the digestive process in the small intestine and the latter being excreted as an excess in the fæces. Thus, the bile is connected with the physical and chemical changes in the intestine. Bile may be best secured by means of a fistulary operation, although it is difficult and dangerous. The bile when fresh is a fluid of a

golden red or a brownish yellow color in the human subject. After being exposed to the air it becomes a dark brown color. It has a strange odor especially if hot and a very bitter taste. It contains some gall cells and some mucous corpuscles usually. Its specific gravity is about 1030. In the gall bladder the bile is mixed with a considerable quantity of mucus of a darker color and very viscous. If dissolved in sulphuric acid it appears fluorescent, being pink in transmitted light, and green through reflected light. After administering anæsthetics an animal's abdomen may be opened and the bile duct ligatured close to the junction with the cystic duct and also close to the intestine. Between these two ligatures there is a division made. The fundic portion of the gall bladder is stitched to the abdominal wall, the fundus being opened and a tube inserted into the gall bladder. In this way the bile may be secured. The bile yields in the case of the human subject from 13 to 15 per cent of solid matter. On the analysis of 100 parts of bile there has been found 86.3 per cent water, 13.7 of solids and of these solids 8.2 per cent of bile salts, 2.5 per cent of cholesterin, lecithin fatty substances, 2.2 per cent of mucus and bile pigment and .8 per cent of the inorganic salts. The bile varies in different animals and at different times in the same animal. It is effected by the length of time it remains in the gall bladder, its reaction is neutral or alkaline. It is characteristic that the proteids are not present. Among the solid matters we find, first bile acids. Taurocholic acid is found in great abundance and glycoholic acid in small quantities in human bile. These combine with sodium to form salts, in the formation of the sodium taurocholate and the sodium glyoholate. They are insoluble in ether but soluble in water or alcohol, the a queous solutions being alkaline in reaction. Both acids contain cholalic acid. 2d, the bile pigments, bilirubin and biliverdin. The former is supposed to be derived from the red coloring matter of the blood being identified by some with hæmatoidin, one of the hæmoglobin derivatives. The latter is derived by an oxidation process from bilirubin. The biliverdin is formed by exposing to the air in a shallow vessel an alkaline solution of bilirubin. The bilirubin is kept in solution in the bile by the sodium salts of the bile acid. 3d. Cholesterin is kept in solution in the bile by the bile salts. This is the chief element found in gall stones. Though fatty looking it is in reality an alcohol, being soluble in hot alcohol and dissolved by the bile salts so that it is in solution in the bile. 4th. The mineral salts including chiefly chloride of sodium, potassium and the phosphates of sodium, calcium and magnesia with traces of iron oxide, silica and copper. In 100 parts of bile Jacobsen found about .1276 of potassium chloride, 2.45 sodium chloride, .598 phosphate sodium .418 carbonate of sodium and .81 per cent of sulphur and .167 phosphate of lime. 5th. The gases of the bile contains sometimes a large per cent of CO_2 ranging from 5 to 50 per cent, and small quantities of O and N.

The secretion of the bile is continuous, but the quantity formed when the stomach is empty is small. Only a low pressure is necessary for bile secretion, for the diameter of the hepatic artery is small and the secretion is not due to the pressure, not being a process of osmosis but of secretion in the hepatic cells.

Heidenhain estimates the pressure of the flow of bile along the ducts to be 15 mm. of mercury; even this small pressure is larger than the pressure in the portal veins; hence, the secretion cannot be due to mechanical pressure. Even when an animal is deprived of food secretion continues. It is largely increased during the digestive process, this secretion beginning to increase almost immediately after taking meal, reaching its highest point

about the third or fourth hour and after gradually diminishing for a few hours, then increases till about the ninth or tenth hour after which it slowly lessens. The amount of food influences the bile secretion, especially in the case of animal food when the secretion is increased, a food consisting very largely of fats diminishing the secretion. According to some experiments there is secreted about 10 grams of bile to every kilogram of body weight daily in the human subject, indicating that there is an active metabolism in the hepatic cells. The secretion is also affected by the blood flow in the capillaries. If blood is injected into the veins it is increased, and if blood is taken from the arteries it is diminished. If the portal vein is ligatured the secretion will diminish until it ceases altogether, causing death. If the hepatic circulation is obstructed the secretion increases and then diminishes. While the blood pressure in the capillaries does not cause the secretion the velocity of the blood current through the capillaries has a bearing upon the secretion, because the action of the hepatic cells depends upon the circulation of the blood through them. The bile is secreted by the hepatic cells and even the water does not depend upon simple filtration because the pressure of the portal vein is less than the pressure in the bile ducts. The activity of the cells depends upon amount of blood received into them. If the blood pressure in connection with bile ducts increases beyond 15 mm. of mercury the secretion of bile continues, but its flow is arrested in the ducts, the bile flow taking place into the blood through the lymphatics, the bile pigment giving to the skin the peculiar jaundice color. The same result may follow, from a ligature of the bile duct, in which case the process requires three or four days. Associated with jaundice is a condition of constipation due to the lessening of peristaltic action, the fæces being hard and yellow colored with an offensive odor. An effect is noticeable upon the activity of the heart, which is much diminished, on account of the lessened activity of the intra-cardiac nervous mechanism and also the respiration becomes slower. The blood corpuscles become dissolved under the action of the bile salts, the pigment being found in the blood and hæmoglobin with albumin in the urine. The formation of bile takes place in connection with the hepatic cells which are closely related to the blood and bile capillaries. The cells are polygonal in shape, the surfaces by juxtaposition, forming grooves, around the sides being found the bile capillaries corresponding with the number of sides, at each of the pointed surfaces being found the blood capillaries. The bile capillaries are much smaller than the blood capillaries that the bile is formed in these cells is evident from the fact, 1st, that if the liver is removed the bile acids and the bile pigments are not found in the blood, and 2nd, the bile acids and bile pigments are not found in connection with any other part of the body and if they are found anywhere else they originate in the liver. The taurin, glycocin and cholalic acids are separately formed and when so formed unite to form the bile acids.

When the blood corpuscles are disintegrated the hæmoglobin is taken to the liver and is converted to the bilirubin, the iron separated being retained in the liver and used in the formation of new hæmoglobin. The bile pigments pass to the duodenum and are mixed with the food. Neither biliverdin nor bilirubin are found in the fæces, but a hydro-bilirubin. The biliverdin arises in connection with the disintegration of the hæmoglobin. In connection with the blood clotting the bilirubin assumes the crystalline form of hæmatoidin the same as bilirubin. If solutions of hæmoglobin are injected into the portal vein the amount of bilirubin is increased in the liver.

The bile salts in solution have the same effect. This substance when hydrated appears in the fæces as stercobilin and in the urine as urobilin. The formation of bile acids takes place in the liver cells. If the bile duct is ligatured the bile that is found is reabsorbed, the acids being found in the blood and urine. It is difficult to determine from what substances they are formed. Nitrogen found in the glycohol and taurin and sulphur in the taurin indicate that some albuminous substance is broken up in their production. These products, as we have said, are absorbed and again through the hepatic circulation, are secreted by the liver. The chief value of these acids is possibly to form a stimulus for cell activity. It is supposed that in addition to this they act upon cholesterin, dissolving it for excretion, and also that they act upon the fats producing an increased fat absorption. When the bile is formed in connection with the cells it is pressed out partly in connection with respiratory movements and partly by muscular activity in connection with the larger and smaller ducts and the gall bladder. Respiratory movements produce pressure upon the liver and gall bladder, inspiration assisting the blood flow away from the hepatic veins. The bile secretion is continuous. It is normally small when the stomach is inactive, immediately after taking a meal the amount is very much increased and this increase is maintained for some hours. It is said that in 24 hours, 2½ pounds are secreted and that the secretion is much more plentiful after partaking of proteid food. The bile accumulates in the gall bladder and its ejection into the intestines appears to be a reflex action, the stimulus being the acid chyme, for it is known that the entrance of an acid into the small intestine is at once followed by a gush of bile, while no such results follow the admission of an alkaline fluid into the small intestine. Nervous influence upon bile secretion is very obscure. The voso-motor fibers are found in the pneumogastric and the splanchnic sympathetics. If the splanchnics are divided or the pneumogastrics in the neck are cut the liver passes into a state of congestion.

Pfluger says that after the division of all the hepatic nerves bile secretion continues; when the bile comes into the small intestine it has very little effect upon the chyme. In the large intestine a part of it becomes decomposed, the balance being excreted in the fæces. The biliary acids are divided up into glycocin, cholalic acid and taurin, the bile pigments into hydrobilirubin and the urobilin to be again absorbed so as to form the pigment, a small part becoming biliprasin. Part cf the urine is united with alkalies in the formation of soaps. The fæces excrete bile acids, cholesterin, mucin and lecithin. A large part of the bile salts are absorbed again, all the absorbed elements returning to the liver to form other compounds.

If in an animal, the bile is hindered from entering the intestine, emaciation follows, but life may be preserved if a large quantity of food is given producing a great appetite. Upon the albuminous or proteid constituents of food bile has no effect unless that by its alkaline reaction it neutralizes the acid chyme and causes the precipitation of any peptone present. The bile prevents the digestion of albuminous matter by the gastric juice at the same time separating the peptones from albumin and preparing the albumin for the digestion action of the pancreatic juice. Upon the carbohydrates the bile has almost no effect, its only effect being to transform the starch solutions into sugar. Upon the fats, bile has considerable digestive power. When the fatty acids are liberated by the pancreatic fluid the bile combines with them to form soaps or emulsions. The fatty acids thus decomposed dissolve the bile, salts uniting with the alkaline bases to form the soaps,

these soaps aiding in the emulsification of fats. These soaps assist in the fatty emulsification of the fats in the intestines, the bile acids causing the neutral fats to become soaps. The fats readily pass through the mucous membrane moistened with bile, hence bile assists the absorption of fats by moistening the mucous membrane of the intestine. Bile also stimulates the peristaltic movements of the intestine. If the bile is diminished the peristaltic action is lessened and the fæces become dry, hence a large increase of bile produces diarrhœa. The bile is freely putrefied although it lessens the putrefaction of the fæces by increasing peristaltic action and thus throwing quickly the putrescent matters out of the intestines. If these matters remained long putrefaction would follow even though the bile is present. Bile has an important bearing on excretion, by removing the waste products of metabolism such as lecithin and cholesterin. The bile acids and pigments become reabsorbed and hence are of further use in the metabolic process. Its chief digestive function is in connection with the fats. It first assists in splitting up the neutral fats and then aids in their emulsification and lastly assisting fat absorption.

If a fistula is introduced so as to extract the bile the fæces are found to contain a large quantity of fat. This is due in some way to the action of the bile acids upon the fats or rather upon the epithelial cells so as to make them active in absorption. In addition to this the bile acts as a destroyer of the pepsin ferment activity. When the chyme comes into contact with the bile and the pancreatic juice it becomes alkaline, preventing the pepsin action and developing the precipitation in connection with the formation of some proteids and acids.

SECTION XII. Pancreas and Pancreatic Juice.

The pancreas is an extended narrow gland lying across the abdominal wall back of the stomach and opposite the first lumbar vertebra. The head of it is in contact with the duodenum curvature and the lower end is in contact with the spleen. The pancreatic duct extends along the whole pancreas, opening into the duodenum below the pylorus. The lining of the duct consists of cylindrical epithelium, the wall being formed of solid connective tissue from which small branches arise, ending in the gland acini. The acini consist of short conical cells. The cell form depends upon its functional activity. When digestion begins the disappearance of the granules takes place, the large part of the cell being clear. During inactivity, especially if prolonged, the granular and clear parts are about equal. Blood vessels from the splenic supply the pancreas, together with branches from the superior and inferior branches of the hepatic and the superior mesenteric arteries.

The blood passes off from the pancreas through thes plenic and superior mesenteric veins. Around each acinus is a plexus of capillaries. The nerve supply comes from the solar plexus non-medullated fibers extending into the pancreas, their endings being unknown. There are also intrinsic ganglia associated with the pancreas. Most of the experiments have been carried on in connection with artificial pancreatic digestion or fistulae in connection with the dog or rabbit. Heidenhain cut out a part of the duodenum into which the main duct opens, stitching this isolated portion to the abdominal wall to form a permanent fistula. The pancreatic juice may be obtained by the introduction of a canula into the duct. It differs from the other juices mainly in the large proportion of proteids in it. It is a clear, colorless fluid, very viscid, under the influence sinogen. By the action of trypsin there are formed the proteoses and the peptones but the process is somewhat different. Solids, under the action of trypsin, do not swell but they erode, the indigestible elements retaining the form. The transformation takes place directly from the proteids to the secondary proteoses, by the hydrolytic process, after which the transformation to peptones takes place. Here the action of trypsin produces a number of nonproteid bodies which are amido-acids. The peptone that cannot be further changed, is called anti-peptone, the balance being hemi-peptone representing the final products of tryptic digestion other than the peptones. It is peculiarly active in alkaline solutions, decomposing the albumen. The trypsin is formed by the decomposition of tripsinogen, as it is not found in the pancreatic cells. Under the action of trypsin the proteids are changed into tryptones, or hemi-peptones as Halliburton calls them, differing from the peptones in various particulars. The fibrin in the pancreatic digestion does not swell, remaining opaque and becoming corroded. The peptic digestion is acid, whereas pancreatic digestion is alkaline, being hindered by accidification especially with the mineral acids. If the pancreatic juice is mixed with sodium carbonate to the extent of 1 per cent the digestion is facilitated, playing the same part in triptic solution that hydrochloric acid plays in peptic digestion. If the pancreatic juice is heated to over 40°C and mixed with hydrochloric acid 2-10 per cent, its action is destroyed. The mixture of the bile with the pancreatic juice seems to facilitate its action. By the action of this trypsin ferment peptones, or rather triptones are produced, the great difference being that instead of producing acid-albumin as in the pepsin, there is produced alkali-albumin. Before the final formation of alkali-albumin the fibrin is changed into products that are intermediate between albumin and alkali-albumin. They are readily dissolved in water and by a weak solution of copper sulphate yield in reaction a deep purple red color. The decomposition yields the amido—acids, leucin, tryosin and the odorous substances phenol, skatol and indol. Indol may arise in connection with proteid decomposition under the influence of alkalies at an increased temperature. It is in the alkaline medium that the germs find a field for development under the influence of trypsin. This pancreatic ferment can convert the proteids into peptones unaided by micro-organisms.

On the other hand, leucin and tryosin are not obtained without these micro-organisms. Indol, it is claimed, is produced under the influence not of the unorganized ferments but by the organized ferment, the micro organism, being necessary for its production, as in a fluid which yields indol, there is always present some micro-organism. In addition to this by the action of the pancreatic juice we find the nitrogenous product, leucin and tryosin Under the influence of the pancreatic juice, the proteid acted upon does not yield nearly the proportionate proteid products. When the product of digestion is divided so as to separate the alkali-albumin there is yielded by evaporation crystals of tryosin. If these are taken out and precipitation produced by a second evaporation, leucin and tryosin crystals are deposited. Thus the proteids under the influence of the pancreatic juice divide up into the proteid triptones and into the substanees that are not proteid or leucin and tryosin. Leucin is a combination of fatty acids and ammonia, whereas tryosin is a phenyl compound closely related to benzoic and hippuric acid. These two represent the fatty acids and aromatic bodies. The pancreatic mixture very soon becomes filled with bacteria. If the ferment is isolated so as to prevent the admission of air germs or if salicylic acid is

used in connection with the juice, the germs are prevented from development and the odor is absent. Thus the pancreatic juice is associated with the formation of indol under the influence of an organized ferment. We have seen that three ferments act upon the carbohydrates, proteids and fats, reducing, splitting up or emulsifying them, the emulsification taking place chiefly in connection with the combination of the three juices, although largely under the influence of the alkali-albumin.

SECTION XIII. Intestinal Juice.

This juice, succus entericus, is believed to be secreted by the glands of Brunner and Lieberkuhn. The information regarding this juice is limited chiefly on account of the difficulty of obtaining it pure. By opening the abdomen and a loop of the bowel cut being across in double section and then by connecting the lower end of the bowel above the part cut across with the upper end of the lower portion so that the intestinal canal is continued, the cut part may be formed into a sac. The Thirry-Vella fistula consists of cutting out a small part of the intestine without injuring the blood vessels or nerves and then stitching the two open ends to the abdominal wall to form a double fistula. By suture the continuity of the intestine is established, the loop being used to collect the secretion. It is a clear, viscid fluid with a palish yellow color and a strong alkaline reaction. The secretion is small and requires stimulation to start it. It is more plentiful in the lower than in the upper part of the intestine. It is freely coagulated by heat and under acid influence, having a specific gravity of 1010. It contains a small per centage of solid, chiefly albumin. mucin and with the carbonate of soda from .25 to .5 per cent and sodium chloride. The invertin ferment converts the cane sugar into the sugar inverted. It is variously described as having a digestive influence over proteids, fats and carbohydrates; others, however, claiming that its action is confincd to the conversion of starch into dextrine and maltose.

The intestinal juice acts upon all kinds of food, its action, however being slow and feeble. The mucin contained in the fluid acts as a lubricator upon the internal surfaces of the intestine, smoothing it so as to permit the contents to pass freely. As soon as the chyme passes into the intestine, the gastric juice ceases to act upon it, the acidity of the chyme producing the flow of bile, pancreatic and intestinal juices. The alkalinity of these juices neutralizes the acidity of the chyme producing the normal alkalinity in the small intestine. In the small intestine all the food elements become changed so as to be prepared for absorption. The alkalinity is greatest in those layers close to the intestinal wall, the internal layers being slightly acid. The hydrochloric acid of the gastric juice precipitate pepsin and glycocholate, the taurocholate precipitating the albumin not transformed into peptones, the peptones and triptones remaining in the solution. The solution that is formed is thick and glairy. At the upper part of the intestine the chyme is of a pale yellow color due to the bile influence, at the lower part it is much paler. As it passes down the alkalinity increases on account of the action of the three juices, the digestive process being nearly completed, leaving very small quantities of undigested food. Under the influence of the alkalinity the triptone digestion takes place. The viscous solution formed by the bile is dissolved but the pepsin cannot act because of the alkalinity in the solution. The remnants of the starch are changed to maltose, the fatty substances becoming emulsified and the albuminous substances changed to leucin and tryosin. This intestinal secretion has no definite action upon the proteids. The sodium carbonates assist in the emulsifying of fats. In connection with the carbohydrates it has an important action. There is an amylolytic ferment more plentiful in the upper part of the intestine acting upon the starch and converting it into maltose and dextrin. In addition the presence of the invertin transforms cane sugar into dextrin and laevulose, and the maltose to dextrose. The double saccharines, cane sugar, milk sugar and maltose, which are found commonly in all diets, are acted upon by the inverting ferments so as to form simpler bodies, the absorption taking place finally in connection with dextrose which is the final product of conversion. Gallstones are often formed in the gall bladder, sometimes smaller obstructions being found in the bile passages. The most common kind of gallstone is composed of cholesterin, sometimes with a little pigment, at other times being colored with pigment. These are crystalline in structure. Another kind of gallstone consists of bilirubin and calcium, these being dark in color. Sometimes the gallstones consist of bilirubin derivatives and sometimes of inorganic salts. These gallstones originate in a neucleus, the matter being collected around this center. The origin of the stone is found in connection with the bile, the cholesterin or bilirubin collecting together instead of remaining in solution in fluid. During the progress in these various changes the peristaltic action of the muscular fibers propells the chyme along the course of the intestine, the absorption of the soluble matters taking place in connection with the blood vessels and the mucous projections of the intestine. Thus, the chyme is gradually transformed and diminished, these processes preparing it for passage into the great intestine. Very seldom is there any quantity of chyme in the intestine, as it passes quickly in absorption and excretion

The chyme as it passes into the intestine comes into contact with the bile and pancreatic juice, changing the acidity into alkalinity. In the human subject the chyme becomes alkaline before passing far down the intestine. The conversion of starch to sugar which was stopped in the stomach begins again under the influence of the pancreatic and intestinal juices and is continued until the greater proportion is digested The pancreatic juice emulsifies the fats, the neutral fats passing to the lacteals. The bile and pancreatic juice provide an alkaline medium, the pancreatic juice furnishing the fatty acid, and the bile dissolving the soaps. Thus the two juices unite in emulsification in the small intestine, the gray colored chyme becoming in the small intestine whitish cream colored. The pancreatic juice thus assists in the changing of fats for absorption in the lacteals. The bile also assists in this process as the removal of the bile by ligature and fistula seems to retard fat digestion, throwing quantities as it into the faeces. The intestinal juice does not possess large emulsifying power. This was shown by a case in which the duodenum opened by a fistula so as to separate the upper and lower parts. Fats placed in the lower part were hardly subjected to digestion, because of the absence of the bile and pancreatic juices, so that fat digestion is largely carried on by the mixture of bile and pancreatic juice. In the intestine there is formed the substances under the influence of micro-organisms, resulting in indol and indican, so that the action of the combined juices in the intestine is modified by the presence of micro-organisms. It is chiefly in connection with the proteids and carbohydrates that this micro-organic decomposition takes place. From the proteids are formed indol, phenol appearing in the faeces and urine. There are also formed in connection with the proteids ptomaines in the process of putrefaction. The principal action of the micro-organisms is in connection with carbohydrates. As the food passes down the intestine there is present lactic acid formed by

lactic acid fermentation. This is supposed to take place normally in the intestine. The presence of free H in the intestine indicates fermentation changes. If chyme is taken from the intestine and kept at bodily temperature, CO and H will continue to be formed indicating the butyric fermentation process. In this way the sugar becomes transformed to the fatty acid group and may be changed to fat. The H acts as a reducing agent, acting on sulphates and producing sulphides and forming faecal and urine pigments. Thus, in the small intestine proteids are changed to peptones and other substances, starch to sugar, and sugar to lactic acid and fat, these passing into the lacteals or the blood vessels, the remainder being excess faeces or urine.

SECTION XIV. Processes in the large Intestine and Passages to the Rectum.

By the absorption of the soluble elements from the chyme it is lessened in quantity, passing into the great intestine to be subjected to the action of secretion arising from glands similar to those of the small intestine. As in the small intestine there are movements of the intestinal contents due to the peristaltic contraction of the muscular fibers of the intestine. The movement, however, is much slower than in the small intestine as the bowel is not so free, being in the greater part of its extent fixed by the peritoneum. The passage of the contents through the large intestine take a much longer time, than is occupied in the small intestine, although the large intestine is only about 1/5 of the length of the small one. It is estimated that from 12 to 18 hours are occupied in the passage through this large intestine. This length of time includes the long time during which substances continue in the caecum, becoming more solid on account of the water being absorbed.

The sharp ridges projecting into the intestines, divide the intestine into a number of compartments, delaying the passage of the contents. The rectum also accumulates the materials, the sphincters preventing the rapid passage. The movements of the large intestine are essentially the same as those of the small, the movements of the large intestine beginning at the point where the small intestinal movements stop, namely, the ilio-cæcal valve. The movements are more simple because of the absence of the loops and the absence of the muscular fibers, to any great extent. The movement is from sacculus to sacculus along the colon, peristaltic contraction, driving the contents from the one to the other, the contraction of the circular fibers being followed by relaxation of the circular and contraction of the longitudinal fibers in the next succeeding sacculus The edges of the ilio-cæcal valve close the caecum so that regurgitation into the small intestine is impossible. When the fæcal contents arrive at the sigmoid curvature, they are upheld by the bladder and caecum so as to press on the sphincter ani.

The nervous connection with the large intestine is as yet unknown. The excitation of the pneumogastric tends to stimulate, while the excitation of the splanchnic sympathetics does not stimulate the activity of the large intestine. No digestive process goes on in the large intestine. The contents are of a distinctly fæcal character, and are acid in reaction, this being due to the acid fermentation of the intestinal contents and not to any acid secretions yielded by the glands in the intestinal mucous membrane. The secretion of the large intestines is composad largely of mucus, having probably no special enzyme of its own. In passing from the small intestine there are still undigested elements but these are mixed with the enzymes of the small intestine which probably act for some time. In the large intestine the contents are alkaline toward the walls, the secretion of the intestinal glands being alkaline in reaction, while toward the middle of the intestine and away from the walls they are acid. In the human subject the intestinal changes consist of the formation out of the waste elements of the food of the bile, and other secretions, of fæcal substances. In the caecum these waste matters become closely packed together on account of the absence of the peristaltic action. The fermentation going on produces certain acids, lactic acid, butyric acid, and also the generation of certain gases as H, surphuretted H, etc. The water becomes absorbed by the blood vessels. In this way the intestinal contents become more and more solid, the water being absorbed. The putrefaction changes also give rise to the formation of certain acids, such as palmitic acid, together with the odorless substances, phenol, cresoal, indol and skatol. The bile that passes down into the large intestine becomes changed into taurin, glycocin, cholalic acid which, together with the pigments and acids of the bile are found in the fæces. These fæces have a characteristic odor which varies in the individual and at different times. This aroma arises from the decomposition of the contents of the stomach and intestines. These may be either acid alkaline or neutral. In the case of dieting upon the carbohydrates and faeces become characteristically acid. If the diet is albuminous they become alkaline. The color also varies with the food. The dark color arises in the case of an animal diet. In vegetable diet a lighter color and in a mixed animal and vegetable diet a yellowish brown. In jaundice the fæces become a dark yellow. Microscopic examination discloses the presence of indigestible materials including ligaments from flesh and cellulose, indigested matters as tissues in fragmentary stages. These tissues vary with the diet. Among the other substances found are mucus, fatty cells, starchy globules, fibers in different stages of decomposition, crystals of the triple phosphates.

There may also be found the acids, pigments, cholesterin, excretin and soaps found in connection with the gastric and other juices. In a mixed diet they contain about 75 per cent of water while in diet upon animal food this is usually reduced to 50 or 60 per cent, about 25 per cent being solid matter, of which about 4 per cent consists of salts, chiefly triple phosphates of ammonia and magnesia. The normal human subject is estimated to pass about 150 to 200 grams daily as fæces. This amount, however, depends somewhat upon the nature of the food. In vegetable diet the amount being largely increased because of the amount of indigestible matter, such a diet in same yielding 450 grams. In the large intestine, CO_2 is the chief gas found together with H, sulphuretted H and carburetted H. In the rectum the fæces remain for a variable time and they are expelled as the result of relaxation of the internal sphincter, contraction of the walls of the rectum and of the abdominal muscles assisted by the fixed action of the diaphragm. The pressure of the fæces upon the mucous of the lower portion of the rectum arouses the impulses. If this pressure does not reach a certain limit the sphincter resists the evacuation. If pressure reaches a certain limit there follows a series of reflex contractions at intervals in the rectum, the contraction extending to the sigmoid curvature of the colon. By these contractions the internal sphincter yields, the external sphincter yielding to the will. The sphincter consists of involuntary muscles, having nerve connections with the sympathetic system and from the spinal nerves from the sacrum. The external sphincter ani is composed of striated muscle tissue and is therefore, at the disposal of the will. Defecation, is therefore, a mixed action partly voluntary and partly involuntary. The voluntary element depends upon the action of the abdominal muscles in the production of pressure. There is a contraction of these muscles similar to expiration but as the glottis is closed the pressure is all brought to bear upon

the abdominal muscles, pushing the contents of the colon down toward the rectum. This pressure does not affect the sigmoid curvature. The spinchter ani protects the anus, the sphincter being normally in the state of tonicity so that there is the capacity of contraction or relaxation depending upon the stimulation. The nervous impulses from the lumbar center kept up the tonic contraction for relaxation follows the division of the nervous connection. If the spinal cord is cut above the lumbar region there is only a slight depression of the sphincter followed by a return to its normal condition. This indicates that the fæcal center is in the lumbar region. This is the center of reflex action depending upon local stimulation and upon the impulses of the higher center under the control of the will. The center may be inhibited and thus the sphincter will relax or it may be stimulated and the sphincter will contract still more. Therefore, in addition to the muscular action there is the inhibition of the lumbar center as a part of the defecation process. Even in diseased brain conditions there is not of necessity, any effect upon the sphincter and if paralysis of the sphincter accompanies cerebral conditions this is due to the reflex inhibition of the lumbar center. These two actions are not sufficient to account for defecation as to the abdominal pressure is prevented by the sigmoid curvature, so that the sigmoid curvature would remain full of matter. In order to accomplish the emptying of this flexure the peristaltic action of the intestine, flexure and rectum is brought into play. In the rectal peristalsis there is a marked peristalsis of the circular and longitudinal fibers. By longitudinal peristalsis the rectum is shortened, the movement being from above downward. As the anus is a fixed base, this results in drawing down the rectal canal. By circular contraction traveling from above downward the rectal canal is narrowed, resulting in the excretion of the contents. As the large intestine and the sigmoid curvature becomes filled with contents, strong peristalsis is aroused in the walls driving the fæces into the rectum and against the sphincter. By inhibition of the lower center the sphincter is relaxed, the abdominal muscles pressing upon the descending colon so that by contraction of the levator ani the fæces are excreted. The reaction of the walls of the large intestine is alkaline but the contents become acid. This is due to acid fermentation in the contents, these fermentations being indicated by the presence of gases. The fermentation depends upon the nature of the food. These fermentation changes are peculiar, being carried out in connection with the micro-organisms. By the process of absorption the contents become hard and dry. They consist of undigestible and undigested food elements with fibrous matters, cellulose connective tissue. To these must be added the productions of alimentary secretion, mucus, albumin fatty acids, salts and phosphates. The pigment of the fæces is derived from the bile pigment, being called stercobilin. If the bile is cut off the fæces become clay colored. These, together with the aromatic substances form the chief elements that constitute the fæces. The act of defecation is under the control of the special nervous centers situated in the lumbar portion of the spinal cord having sensory and motor fibers to the rectum and defecation muscles. This center is subject to the influence from the higher centers. This is evident from the fact that in comatose conditions the sphincter becomes paralyzed and the defecation is no longer under the control of the will, becoming entirely involuntary.

The nerve supply to the rectal muscles consists of motor and inhibitory fibers some from the nervus erigens through the hypogastric plexus and some from the chord of the lumbar region through the sympathetic ganglia, the inferior mesentric ganglia and the hypogastric. This, however is disputed. The paralysis of the sphincter being said by some Physiologists to be due to the inhibition of the lumbar center. In the rectal movements we find distinctation of the longitudinal and transverse fibers, the longitudinal movements being directed from above downward, causing the shortening of the rectum, the transverse movements traveling in the same direction, but following the other contractions, causing a narrowing of the rectum and thus pushing onward the matters within the rectum. The special changes in the large intestine are bacterial. Bacteria are usually prevented from being active by the strong acid reaction of the juice. In connection with dyspepsia we find, however, certain bacteriological developments in the case of the carbohydrates. In the small intestine the normal alkalinity of the secretion favors such bacteria. It was formerly supposed that the proteid decomposition involved such a bacterial development. But recent experiments have indicated that the contents just before passing to the large intestine are acid, if a mixed diet is used, acetic acid being formed in connection with organic substances normally about 1-10 per cent. This acid must have arisen from bacterial decomposition of the carbohydrate and not of the proteids. The formation of such acid preventing proteid putrefaction. This, however, may be changed in the case of a large proportion of proteid in the food or a deficiency in the absorption of the small intestine. In the large intestine the acidity is destroyed by alkaline reaction so that in the large intestine there may be proteid putrefaction. This putrefaction while normal may vary considerably within definite limits. The products thus produced are leucin, tryosin, indol, lactic acid, sulphuretted hydrogen, etc. Some of these are absorbed in the blood and passed to the urine, others stimulate peristaltic action.

If the stomach and intestines are removed from the body and subjected to stimulation the result will be movements of a peristaltic nature. Therefore, the entire alimentary canal has the power automatically of carrying out its own movements. If the vagus nerve is stimulated very strong peristaltic movements will result in the oesophagus, the stomach and intestines. The normal stimulation is the presence of food in the intestine. It is supposed that by stimulating the mucous membrane impulses are sent up that descend along the vagus, thus reaching the stomach and the upper part of the lower intestine by the terminals of the two vagi and to the intestines by the posterior vagus which passes through the solar plexus and the mesenteric nerves. Even after the division of both vagi, however the movements still continue. The nerves of the vagi, therefore, act as accelerator fibers to the alimentary canal. Similarly, the splanchnics act as inhibitory fibers so that by stimulating these fibers the peristalsis may be slowed and even stopped. This is explained by the fact that while the splanchnics have fibers for constriction to the intestinal blood vessels they also have inhibitory fibers for the muscular coat and the vagi have accelerator fibers for the muscular coat and dilator fibers for the blood vessels. In the rectum the muscular coats have different nerve connections the longitudinal coat being controlled by the nervi erigentes through the hypogastric plexus coming from the spinal cord by the anterior roots of the 2d and 3d sacral nerves. The stimulation of these contracts the longitudinal fibers of the rectum. The circular coat is regulated by nerves leaving the spinal cord by the anterior roots of the lower dorsal and first two lumbar nerves passing through the inferior mesenteric ganglia, the hypogastric nerves and the hypogastric plexus. Irritation of these fibers results in contractions of the circular coat. Thus the rectal movements are more closely connected with the central nervous system than the rest of the alimentary canal. In the small and large intestines the nervous system supplies and regulates the movements without originating them, while in the rectum the lumbar region and its fibers carry

out the rectal movements by reflex action. In diseases of the central nervous system it is here that constipation is produced, the fæcal contents accumulating in the sigmoid flexure and the colon. In addition to the stimulation produced by the food contents in the intestines the deficient oxygenation of the blood in the alimentary walls arouses peristaltic action. If the blood is interfered with by clamping the aorta peristalsis becomes violent. Hence, in death by asphyxia, the interference with respiration produces a discharge of faeces. Thus the absence of blood or deficiency of oxygenation stimulates peristalsis.

SECTION XV. 4.—Absorption.

We have found that there are different processes through which the food passes in being made soluble so as to be capable of holding in solution certain substances. In considering this question of absorption, we must regard the blood as exerting on one side of an organic membrane certain pressure while there is another fluid on the other side holding in solution certain substances. If we have two fluids that can be mixed aside from any chemical changes and if these two fluids are poured together there will be diffusion between the two fluids till there is a uniform mixture of the fluids. There will be diffusion even if the fluid that is poured on the top is lighter because part of the heavier fluid will rise to mix with the lighter fluid. It is very similar to the diffusion of gases, the difference being that liquid diffusion requires much more time. For example, it will take seven weeks to diffuse a solution of common salt with a solution of sulphate of copper poured upon it; it will take longer time to diffuse a solution of water with an overlying solution of albumin. This diffusion will be increased by a rise in temperature. If there is a separation of a porous character between the fluids, the fluids will diffuse through the pores representing a large number of fluid channels. In this case we find capillary imbibition without volmetric increase. This differs from the imbibition with change of volume as in the case of gelatin absorbing water solution the water passing into the interstitial spaces. It is in this way that albumin and starch together with connective tissue absorb fluids. If tendons are dry they will absorb more than twice their weight, cartilages and connective tissues more than three times their weight. If the membrane is dry that is brought into connection with the fluid it will be distended, the distension being greater in the water solution than in a saline solution, the water being absorbed and the salt concentrated. There is an attraction for the water in the pores, this attraction being found in the walls of these canals while the saline solution passes through the center of the pores. In this way when brought into contact with an animal membrane there are two fluid layers, (1) next to the walls consisting of water and, (2) the layer in the center containing a salt solution. If two fluids are separated by the membrane while both fluids are subject to the same pressure there will be diffusion current passing in both directions. If we have water and a solution of saline matter the water will pass more freely so that the saline solution will increase in volume. This will go on until the saline matter diffuses equally on both sides of the membrane. Glutinous substances will not pass through membranes unless very slightly, but they will attract a large proportion of the fluid from the other side of the membrane. If the glutinous matter is mixed with some substance having a crystalline structure, then the crytalloid will diffuse more slowly than if separate and the glutinous substance will diffuse much more slowly than if alone in the fluid. If a solution of albumin is mixed with salt, the salt will almost entirely diffuse out of the albumin solution. In this way colloids and crystalloids may be separated by diffusion. When the diffusion of fluids takes place under the influence of pressure through animal membrane, it is called filtration. If the pores of the membrane are large, then not only the fluid but blood corpuscles and milk globlets will also pass through. Usually, however, the membrane is more delicate and then morphological elements are arrested. It is under the influence of diffusion and filtration principles that absorption takes place. Aside from the fats it was formerly supposed that absorption was a simple physical process, there being either osmosis or filtration or both combined. This has given place to the theory which takes account of the activity of the epithelial cells acting according to the living properties of animal membranes. Diffusion and osmosis, however, partially explain the processes. When two mixable fluids are separated by a membrane there is a certain diffusion through the membrane and this is called osmosis or dialysis, this diffusion taking place independently of pressure on either side. There may be as we have said, pores in the membrane but this is not necessary, as the membrane may imbibe the fluid and thus by the swelling of the membrane prepare the way for osmosis. If two different substances are separated by a membrane, diffusion takes place until equilibrium is established except in the case of certain soluble substances that are not dialyzable. Hence, Graham divides these soluble substances into two classes, (1) dialyzable, called crystalloids, and, (2) non-dialyzable, called colloids. Gelatin is the best example of the latter. In the case of the crystalloid an osmometer can measure the rapidity of the osmosis. In the case of a strong solution of sodium chloride placed in a tube with a membrane at one end and then placing the membrane in contact with distilled water the diffusion will take place both by exosmosis and endosmosis. There is much greater water diffusion than salt diffusion, hence the endosmotic equivalent is estimated by dividing the water by the salt, $\frac{\text{water}}{\text{salt}}$, this approximately representing the dialytic rate. Thus, in osmosis there must be two mixable liquids with a separating membrane. Thus, we find in the process of absortion the blood and lymph on the one side and the soluble contents of the starch and intestine on the other. The food substance we have considered in the different stages of digestion, the elements being separated in such a way as to leave the nutriment in the fluid solution, the insoluble matters becoming soluble in water and the fats being emulsified so as to be minutely divided. This prepares these substances for absorption. To this process of absorption we apply the principles of physics bearing upon diffusion. These nutritious matters are as yet outside the body in the passage through the alimentary canal. As we have seen, digestion consists of the conversion of proteids that are non diffusable into diffusable peptones by the emulsification of fats so as to prepare for the absorption process. This process takes place, (1) in connection with the alimentary canal and, (2) in connection with the other organs.

(1.) During digestion in the stomach, water, salts, sugar and peptone pass into the blood vessels in the gastric mucous membrane and are, by them, conveyed to the liver. Absorption takes place in the stomach and in the intestines, and it is especially in the small intestine, that absorption takes place in connection with the capillaries of the portal system, the absorbed substances being carried into the liver and by the lacteals into the lymphatic system, being finally transferred to the blood, and through the blood conveyed to the different tissues. Absorption that takes place directly through the blood, reaches the tissues much more quickly, as the lymph flow is so slow that it takes a long time to pass through the lymph. All nutrient matter passing through the blood, must pass through the liver by the portal circulation. These two channels representing the great fluid circulations of the body, namely, the blood and lymph.

Magendie showed that not only the lymphatic system but also the blood capillaries are engaged in absorption by showing that if the thoracic duct is ligatured and a soluble poison passes to the intestine, the death of the animal will take place as soon as normally without any ligature.

THE BLOOD.—The mucous lining of the stomach and the intestines is abundantly provided with blood vessels lying directly underneath the epithelial lining. If injections are made the capillary plexuses may be distinguished by the action of poison upon them. In the stomach the capillaries are found to form networks of irregular structure. In the small intestine the capillary plexuses exist in the form of loops changed into the villi while in the large intestine the network of capillaries is regular. These capillaries are normally filled with blood slowly moving and exerting a pressure on the internal surface, separated by the vessel walls, connective tissues and epithelium from the chyme which contains the soluble food matters. In this way, by the close connection of the blood and the solution containing certain substances we find results in the passage by absortion into the blood, of water, salts and peptones, these passing in the blood to the liver. This interchange between the blood and the lymph in the respective systems and the fluid contents of the stomach and intestines takes place on the basis of the principles of diffusion. When the blood and the lymph becomes deficient in water, salt and saccharine matters, these substances pass from the fluid in the intestines. The diffusion takes place on the basis of the difference in the substances found in the respective fluids. The rapidity of the diffusion process depends to some extent upon the motion of the fluids, the peristaltic action of the stomach and intestines keeping the digestive fluid in constant movement. It is a process of diffusion and not of filtration, subject to pressure. The blood and lymph and the intestinal fluids are in motion and hence are brought closely together, separated by the membrane. The concentration differs on the two sides of the membrane. As the blood and lymph move and as the intestinal contents move diffusion is favored. This would account for the diffusion and absorption of water, salts and sugar. This process of diffusion does not account for the absorption of fatty substances and albumin. Albumin will not readily pass through a membrane by diffusion, and only if the fluid upon one side of the membrane is rich in albumin while on the other side there is none. There is a large percentage of albumin in the blood and lymph, about 7 and 3 per cent respectively. This albuminous matter however, by the digestive processes is changed into peptones, these being readily soluble in water and thus prepared for absorption in connection with the cellular walls of the vessels. The living tissue between the soluble substances in the stomach and intestine and the blood of the capillaries consists of living cells, these cells being continuously active. Their activity implies the capacity of cellular absorption according to which the cells have the power of selecting materials. This absorption occurs to a slight extent in the mouth becoming more rapid in the stomach and is greatest in the small intestine, being less active in the large intestines.

LYMPH AND CHYLE.—The mucous lining of the small intestine is covered over with small conical projections of the mucous membrane, very numerous in the human subject being said to number four million. These form conical or cylindrical processes, projecting about 1 mm. out from the mucous lining. They consist of delicate adenoid tissue identical with the lymphatic glands. In the reticulum we find lymph corpuscles. In the center of the villus we find an open space freely connected with the retiform tissue, towards the base, the villi becoming lacteal, the villus being abundantly supplied with blood vessels. On the internal surface of the villus there is a delicate covering of epithelium cells forming a large lymphatic cavity. At the base, there is a wall and valves constituting a lymphatic vessel. Between this vessels, called lacteal, and the membrana propria, there are fine muscular fibers, some longitudinal and some circular. When there is a rich blood supply during absorption the villus becomes hard and firm. During the process of absorption in connection with fatty substances fat particles are found in these epithelial cells or at the cell margins and the lymph spaces, in the center of the villus or in the lacteal. The fat molecules pass from the fluid in the intestines into the lacteal. Some Physiologists suppose that they are driven through the cell or between the cells by the force of peristaltic movements. It is more likely, however, that these cells by protoplasmic action absorb the fat and pass through the cells filaments, these filaments being emptied of their fatty contents by a series of sucking movements.

Definite amœboid movements have been noticed in these processes. When these fatty substances reach these filaments the contraction of the muscle fibers of the villus empties the blood out of the villus and pushes forward the substances to the large lymphatic cavity, thence to the lacteal and from thence to the neighboring villa and the lymphatic vessels. When the contraction of this filament ceases relaxation follows, the blood once more entering and producing the dilatation of the villus thus relaxing the lymph spaces. There is no regurgitation of the fluid passed into the lacteals because of the valves, and hence any substances left in the cells will be attracted into the lacteals. As soon as these lacteals become filled another action will suck the substances into the lymphatics. In this explanation no account is taken of the adenoid tissue of the villus. According to a more recent theory this tissue is very active in the absorption of fatty substances. The lymph corpuscles of the retiform tissue are supposed to project filaments between the cells, these filaments sucking in the particles so as to convey them to the cells. This is said to be proved by the fact that partially solid particles are taken into the cells. According to this theory the absorption process would go on slowly in connection with the lymph corpuscles independent of the epithelial cells. Accordingly the filaments of these epithelial cells are supposed by Schafer to be continuous with the filaments of the lymph cells connecting with the lymph tissue of the lymphatic spaces. According to this the fatty substances are first absorbed in the epithelial cells and then passed through the filaments to the lymph cells from thence to the the lymph spaces. If we suppose that the muscle fibers are active this would account for the passage of these particles in one direction from the epithelial cells to the lymph cells and on to the lymph spaces. It is not only in fat absorption that these villi are active, this would permit the free passage through the two cells from the intestine to the lymph vessels. The blood vessels and lacteals of the villi also absorb peptone and other substances, produced by the digestive process, this absorption through the blood vessels and the cells being carried on within the limits of their capacity of absorption, the surplus that cannot be thus absorbed being excreted in the fæces. In this absorption we find the activity of the mucous epithelium. If peptones are injected into the blood they will soon be excreted by the kidneys indicating that they are taken into the epithelial cells and then transferred to the lymph cells that lie beneath the epithelium cells, being considerably modified during digestion so as to assist in the cell absorption. The same change takes place in the large intestine. Voit has shown that nutritive fluids containing sugar, peptone, salts and even dissolved albumin may be absorbed in connection with the rec-

tum. Intestinal absorption takes place only within definite limits, hence, the fat is absorbed only within these limits. Voit for example, found that a dog could not absorb over 300 grams daily. Beyond this limit there is excretion of the excess undigested in the fæces. Large proportions of sugar taken into the system and subjected to digestion and absorption produced diarrhœic conditions due to excessive peristaltic action arising from the stimulation by the acid formed or by increasing the absorption in connection with the vessels. Similar diarrhœic conditions are produced by the excessive use of starchy substances producing an excessive acid fæcal matter. The lacteals mentioned in connection with the absorption of fats represent a part of the lymphatic system found in connection with the small intestine. These lacteals differ only from the general lymphatic system in the character of the fluid, chyle of a milky white color found in these lymphatics. The lymphatic system originates in minute capillary vessels, these vessels being found in the human subject all over the body wherever connective tissue is found in which are the interspaces in which the lymph is collected. The lymph capillaries are joined together into bundles passing into the smaller lymphatic vessels running through the bed of connective tissue until after passing through the larger lymphatics they are all united with the two main lymphatic ducts the thoracic duct and the right lymphatic duct opening into the junction of the subclavian and jugular vein on the left and right sides. As the lymph moves gradually from the lymph spaces to the venous circulation it is changed somewhat under the influence of the glands and the lymphatic vessels. The lymph differs in the various organs in which it arises but the chief variation is that found in the lymph arising in connection with the alimentary canal called the chyle. When digestion is not going on the fluid formed is the normal lymph. During digestion it possesses certain peculiar properties. During the digestive process, particularly if fatty substances have been taken in connection with a meal the lymph becomes milky associated with the villi and mesenteric lymphatics called the lacteals. If the food has no fat the fluid is clear and slightly yellow with no distinction from the lymph. The mesenteric lacteals unite in the formation of larger vessels which pass into the mesenteric lymphatic glands. As the vessels pass out of these glands they form the lymphatic trunk with a dilated portion called the receptaculum chyli, passing thence to the thoracic duct. Into this duct also pass lymphatics from the pelvic organs and the extremities of the body. This main thoracic duct after penetrating the diaphragm in the thoracic cavity unites with the venous system at the junction of the left subclavian and left internal jugular vein. This fluid passes into the thoracic duct where it is mixed with the normal lymph, the milky character being retained on account of the predominance of the chyle. Chyle differs from ordinary lymph in the amount of fatty substance it contains, the amount of fat varying the kind of food taken. The increase in the fatty substances is due largely to the neutral fats. The chyle from the receptaculum chyli is normally after a meal slightly alkaline with a specific gravity varying from 1018 to 1027. Examined microscopically it is found to contain in the fluid large numbers of fat cells containing minute particles very similar to the white blood corpuscles. These are called lymph corpuscles. These cells appear in the chyle after passing into the lymphatic vessels and glands. After removal from the receptaculum or the duct,chyle coagulates very much like blood, consisting of a clot and the milky serum. When the lymph is taken from the duct just before passing out of the duct into the venous circulation it is of a slight reddish hue and on coagulation is more consistent and of a reddish color. This is probably due to the mixture of chyle with red corpuscles. In the chyle we find not only the cells but also very minute granules with characteristic amœboid movements, these forming the characteristic constituents of chyle. This minute granule division exists only in the lacteals. The chyle thus consists of lymyh with the addition of a large proportion of these fat granules. The composition of the chyle is found to be in the human subject, in 100 parts, 90.5 of water and 9.5 of solid. Of this solid matter there is about 7 per cent. of albumen, 1 per cent. of fat, and 1.5 per cent. of salts and extractives with a small per cent. of fibrin. Thus, the chyle contains from 3 to 4 per cent. more of solids than normal lymph, this being due to the presence of fat. The amount of fat varies, there being often as much as 5 per cent. The increase of fat is largely due to the neutral fats. It is said that there is a larger amount of soaps, lecithin and cholesterin than in the lymph. Some of this fat exists in the globule form of various sizes, the largest amount being in the form of minute granules, these granules being characterized by the Brownian movements. These granules of fat form the molecular basis of chyle. This we find, is the condition of the fat which becomes very finely divided in the intestine preparatory to its passage into the lacteals in granular form. Thus the chyle is lymph with a large quantity of fat added. The quantity of chyle daily formed cannot be accurately estimated. It is said that an amount equal to the whole volume of the blood is passed through the duct in a day, one half of this amount from the lacteals in the alimentary canal. The amount of milky substance depends upon the fat in the food. Even in the absence of fat, water, salts sugar and peptones pass into the lymph spaces and the lacteals. These substances, however, probably are rapidly absorbed again in the blood vessels so that probably only when mixed with fats, do they pass into the lacteals of the villi and thence to the glands as chyle. Along with this chyle, the real lymph exuded from the capillaries and not absorbed in the tissue, passes into the ducts. The chyle moves from the roots of the vessels in the direction of their trunks. If poison is injected beneath the skin into the connective tissue, it rapidly passes into the lymph spaces and thence into the lymphatic circulation and the blood. By dividing the lymphatic vessels, the flow is found to be slow and continuous. The lymph movement is much slower than the blood: in the lymphatic vessels of the neck, it is estimated about 4 m m per second. The producing cause of the lymph movement is the pressure of the blood in the arteries. The flow is roots up under the influence of the pressure, the pressure being greater at the kept of the small vessels and less in the main trunk so that the flow is from the smaller to the larger vessels. We have seen that there are two channels opened up through which the digestive products by absorption pass to the system, the one through the capillaries and the other through the lacteals. In the first case they pass into the portal circulation by which they are conveyed to the liver. In the second case they pass through the lymphatic system, and afterwards fall into the general blood circulation. The peptones and the sugar pass readily through the capillaries of the villi into the portal system, whereas, the fat after emulsification being unable to pass through the capillaries, passes into the lacteals and thus finds its way into the lymphatic system.

The absorption takes place in the stomach and small and large intestines.

1. The stomach.—Absorption in the stomach takes place in connection with water, salts, sugar and dextrines that have been converted by salival action, also the proteoses and peptones formed under the action of pepsin. There may be also an absorption of fluids swallowed in such a condition as, for example, alcohol. Recent experiments indicate that absorption does not take place freely in the stomach. By isolation of the stomach and introducing a fistula just below the pyloric opening into the duodenum, food can be introduced into

the stomach and removed after digestion so as to observe the changes that take place. It has been found that water, when introduced alone into the stomach, is not absorbed. So soon as the water alone enters the stomach it passes to the intestine almost entirely, none or almost none being absorbed. In the case of alcohol, on the other hand, there is found free stomach absorption. The salt solutions, as for example, sodium iodide are absorbed very slowly until concentrated about 3 per cent. Absorption is found to be assisted by the use of mustard or alcohol which produces stimulation of the mucous lining.

The different forms of sugar are absorbed in the stomach, the absorption being more marked when the solutions are concentrated to the extent of 5 per cent. Absorption takes place more rapidly if mustard or alcohol is used, indicating that normally, absorption of the peptones and sugar does not take place readily. There is no digestion of fats in the stomach because emulsification must precede fat digestion and this takes place in the small intestine.

2d. The Small Intestine.—It is here that the sugar and peptones are immediately absorbed. When the partly digested food products reach the upper part of the duodenum they are acted on by the juices These juices act very strongly on the proteids, carbohydrates and fats and as the digestive process takes considerable time, the act of digestion cannot be very complete. It is estimated that not less than two hours is occupied in the digestion in the small intestine and this may vary to six hours, much longer time being necessary before it is all passed out of the small into the large intestine. During this process conversion has taken place into soluble form being brought into contact with the mucous membrane which has a large number of villi and also folding valvulae. Experiments have proved the rapid absorption of sugar, peptones and salt solutions, it being estimated that 85 to 90 per cent of the proteid matter is absorbed during the passage through the small intestine.

Water and Salts are also freely absorbed, a large part of the water and salts being used in connection with secretion and the maintenance of the fluid condition of the chyme.

3d. The Large Intestine.—Absorption takes place freely in the large intestine The passage of the contents takes place very slowly from 10 to 12 hours being occupied in the passage through the intestine during which time they are changed from the semi-fluid condition to the solid consistency as faeces. When entering the large intestine there is usually a small proportion of sugar, proteids and fats. Part of these is decomposed in connection with bacterial action, part of it being absorbed even before the commencement of decomposition. The absorbing power of the large intestine is indicated by the use of enemata, large quantities of distilled water and other fluids being readily and rapidly absorbed. Even soluble proteids may be readily absorbed in connection with the rectum although no ferment is known to exist that can act upon these. In the same way fats and sugar may be absorbed by injection.

Proteid absorption.—There is absorption of the [illegible]oteids in the stomach and the small and large intestines, more particul[illegible]y in the small intestine. The final products of the digestive action o[illegible]he ferments are peptones and parapeptones. By the action of the trypsi[illegible]here are produced the amido-acids, tryosin and leucin. The proteol[illegible] action, therefore, presents the soluble proteose, peptone and tripton[illegible]which are easily absorbed. Proteids may be absorbed, however, in othe[illegible]ways. For example, proteid dissolved, such as egg or muscle in solutio[illegible]njected into the rectum will be readily absorbed without any digestive ac[illegible]. In the peptic digestion syntonin is formed and in all probability it i[illegible]rectly absorbed as such, but the large proportion of the converted substa[illegible] are changed to peptone. This absorption takes place not simply by dialysis as the albumin of egg that is non-dialyzable becomes readily absorbed in the intestine. Its rapidity also makes it impossible that the process should be simply dialysis. In some way there is activity of the epithelial cells in the absorption of these peptones. They are then passed directly to the blood capillaries, for if the lymphatic duct is ligatured peptone absorption goes on normally. Although the absorption takes place directly to the blood, there does not seem to be any of these substances in the blood when examined. If they are injected into the blood they act as obstacles to the blood circulation and impurities resulting in certain cases in death. If thus introduced directly into the blood they pass from the kidneys without any assimilation. This seems to indicate that in passing through the cells, these peptones are changed in some way so as to form practically new substances said to be serum albumin. If this is true the process is one of dehydration. If a loop of the intestine is taken out of the body and artificial digestion is kept up in connection with the mesenteric arteries the loop will live for a time. If peptone is placed in the loop a considerable proportion will disappear but will not be found in the circulation that is kept up in the loop. The peptone does not disappear in the blood, indicating that the peptone is changed before passing from the cells to the blood. By the absorption of proteids, the kidney excretion of urea is increased. If the thoracic duct is ligatured to prevent the chyle from passing to the blood and if the animal is fed on proteid the urea increase will still be observed. This indicates that the soluble proteids do not pass into the chyle but into the blood.

SUGAR ABSORPTION.—The absorption of the carbohydrates takes place largely in the form of sugar and dextrine. By the intestinal juice starch is changed to maltose and dextrin and by the inverting into the dextrose. Cane sugar is transformed to dextrose and laevulose. Milk sugar is converted to dextrose and galactose. Thus in the form of dextrose or laevulose the absorption takes place. The sugar found in the blood is the dextrose form. In this form oxidation takes place readily in the tissues. If cane sugar is injected into the blood it will not be assimilated but will be excreted in the urine, while dextrose so injected will disappear. The absorption power of sugar differs, the absorption not being directly proportional to the diffusibility. Absorption increases with the concentration until the maximum of 5 per cent is reached. This indicates that it does not take place by a simple diffusion. Hence, it is supposed to be similar to proteid absorption depending on the activity of the epithelial cells, passing directly from the cells into the blood. If there is a large quantity of sugar in solution in a large quantity of water, absorption takes place also into the chyle, the water passing to the lacteals and carrying the sugar with it. In the passage into the blood from the cells there is a change, the maltose which forms the largest proportion of sugar in the chyme, being changed to dextrose or the blood form of sugar.

FAT ABSORPTION.—Fats are absorbed largely in solid form in the condition of emulsification, so that the process of absorption is not that of osmosis. The epithelial cells of the villi in the small intestine are especially active in connection with fat absorption. The fat globlets are drawn into the cells and passed through the cell substance, passing then through the cells into the villi-substance. There is a large lymph capillary terminating at the top of the villus, the villus substance lying between the epithelium and the lacteal. These fat particles pass from the epithelium cells to the lacteal and thence to the lymphatic system. Thus, the fat passes largely if not altogether into the lacteal system, the adenoid tissue containing a number of minute lymph canals in connection with the lacteals, the fluid exuded from the blood capillaries keeping up a constant stream of lymph through the villus to the lacteal. By estimating the amount of fat taken in a meal and the amount found in the faeces as well as the amount found in the thoracic duct it is estimated that 60 parts out of every 100 parts of fat which leave the alimentary canal pass into the thoracic duct and into the venous system. The question is, what becomes of the balance? Some say that it passes into the portal circulation, as there is a quantity of fat found in the portal blood during digestion. A large proportion of the fat however passes through the lacteals.

WATER AND SALT ABSORPTION:—Only a very slight absorption of water takes place in the stomach. Along with the peptones, sugar and salts there is an absorption of water. In the small intestine there is a free absorption of water and salts. Heidenhain has proved that the absorption of water and salts in the small intestine takes place in connection with the blood vessels and not through the lacteals unless where a large quantity is taken, when the lacteals absorb some of it. In the large intestine the water is absorbed in connection with the blood, the epithelial cells attracting the water into them and then giving them off into the blood. The fats are emulsified by the bile and the pancreatic juice in the intestine, the soap formed, aiding in the emulsification. The emulsified fat enters into the columnar cells in the villi. The margin of the cell is thought to be active in the entrance of the fat, the leucocyte being active possibly in amoeboid movements. The bile is supposed to assist the passage of the fat particles by bringing the fat more closely together and acting upon the cell substance. Inside the columnar cells these fat particles can be seen in the living cells, the particles occupying the spaces in the protoplasm. Some suppose that the fat enters in very minute particles and then that these are joined together into larger globules.

Out of the columnar cells the fat passes to the spaces in the reticular tissue, filling up the reticular spaces which are vacant, many of these spaces being filled by the migratory leucocytes. As soon as the fat passes through the cell base it enters into these reticular spaces, the passage taking place probably by amœboid movements. From the reticular space it passes to the lacteal cavity, part of the fat being changed in its passage into the minute division known as the molecular base. It ceases to be emulsified fat at this point and becomes chyle. In this lacteal root we find not only fat but also the proteid that constitutes the chyle, this proteid and other substances being derived from the blood capillaries. In the reticular spaces are found migratory leucocytes, some of them passing between the cells, entering into the intestine. Some pass into the villus cavity. From this some have concluded that the leucocytes play, an important part in fat absorption, taking up the fat and then moving back with the fat absorbed so as to carry it to the lacteals and the lymphatics. This, however, cannot be carried on to any great extent, as the number of leucocytes is too small to admit of their carrying on all the fat absorption. The base of the lacteal cavity opens into the lymphatic vessel in which the lymph flow takes place. By the peristaltic action the lymphatic vessel is emptied of its lymph and the lacteal is also emptied of the chyle. The muscle fibers of the villus also act as a compressing force to empty the lymphatics and the lacteal vessels. These fibers are all running in one direction, parallel to the vertical axis of the villus. By contraction the villus is shortened so as to empty the lacteal. By relaxing the villus is lengthened and the lacteal opens to be again filled. According to others, the contraction of the fibers and the shortening of the villus makes the villus broader, and thus permits the lacteal to be filled; whereas, the relaxation lengthens the villus and narrows it, thus emptying the lacteal. During the digestive process these contractions and relaxations are going on so that there is a constant process of emptying and filling the lacteals. By the contraction of these muscle fibers in the villus compression is brought to bear on the columnar cells. While on relaxation of the muscular fibers the cells will also relax, these muscular contractions and relaxations assisting in the passage of materials from the intestine into the cells. In the case of the substances which as distinguished from the fats are, diffusable, including water, salts and peptones, there is absorption into the blood vessels rather than into the lacteals. The capillary blood vessels are lying immediately beneath the membrane. During the digestive process the blood vessels are filled. There is a transudation of fluid from these vessels into the reticular cavity and the lacteals and a similar transudation from the external and the internal surfaces of these capillaries. Passing through the epithelial cells of the reticular cavity, the diffusable substances are diffused through the vessel walls, the diffusion taking place in two stages.

1st. From the intestine to the spaces passing through the epithelium cells; and 2d, from the lymph spaces to the capillaries. These substances including peptones pass slowly, the diffusion taking place on the principles of physical osmosis subject to the Physiological structure of the membrane separating the fluids. The rapidity of this diffusion can be determined by placing solutions of these substances in the intestinal loop and carefully watching the process of diffusion. The diffusion will take place at different rates depending on the substances and the condition of the membrane.

2. ABSORPTION BY MEANS OF THE OTHER ORGANS OF THE BODY.

Absorption takes place in connection with (a) the skin. Absorption by the skin takes place in connection with gases and to some extent fluids and semi-fluids and solids. By the absorption of gases like sulphuretted hydrogen through the skin after every other passage is closed, the animal may be poisoned. In the case of liquids it seems almost impossible that fluids should be able to make their way through the epidermis and the fatty coating of the outer surface. In addition to the strong coating the pressure is always very strong from the internal surface. This, however, does not prevent the demonstration of the passage of water and even of fatty and oily matter through these surfaces, particularly if associated with mechanical stimulation. Mercurial solutions by external massage may be made to enter freely into the tissues from which diffusion will take place. These substances pass through and into the ducts of the sebaceous layer npon the surface, being absorbed into the vessels found in connection with these glands. It is also possible for certain solid substances in solution to be absorbed in this way, as in the case of saline substances. Any of the mucous surfaces to which such substances are applied will freely absorb them, as the rectum and urethra. The vapor arising from a bath, as for example, in iodine of potassium baths may be absorbed in this way, the substances appearing very soon in the urine. Alcohol, ether and turpentine may also be feely absorbed by rubbing on the skin.

(b) SEROUS ABSORPTION:—The Serous surfaces represent a large tissue or lymph spaces and their stomata communicate with the lymphatic vessels. During inflammatory stages there is an accumulation of fluid in connection with these serous surfaces such as the peritoneum or pleura, the fluids being absorbed. The absorption takes place readily in connection with the openings at the margins of the lining cells. The fluid that is found in connection with these serous membranes is very similar to the lymph. It is alkaline in reaction, containing about 4 or 5 per cent of solid matter.

(c) PULMONARY ABSORPTION:—In the lining membrane of the air vescicles the absorption of gases takes place very readily. Also fluids are absorbed, although not so freely. For example, water passing into the air passages and the air cells may be absorbed without any detriment if not excessive in quantities. In the case of persons engaged in certain occupations small particles of foreign substances, for example, steel fillings may be found in the lung tissues having been breathed into the lungs and absorbed by or in connection with the delicate cells lining the surfaces of the air cells.

(d) THE TISSUES IN GENERAL:—From the blood nutrient matters are constantly passing out into the tissues and the amount of this matter is always in excess of the tissue requirements. In addition the injection of solutions underneath the skin brings these solutions into close relation with the connective tissue, these solutions being absorbed and passed into the system. This fact lies at the basis of the hypodermic method of subcutaneous injection of medicines. In addition the constant activity of the tissue corpuscles leads to the formation of waste matters and these together with the excess of nutrient matters lie in the tissue spaces from which they are carried off partly by the blood vessels and partly by a special set of vessels communicating with the tissue spaces, the lymphatic capillaries by which they are carried into the general lymphatic circulation.

CHAPTER VI.—SECRETION AND EXCRETION.

SECTION I.--Introductory.

1. SECRETION.—The term secretion is applied to the fluid products of glands. The term gland is used to designate a number of structures that differ in organization. The gland consists of a structure composed of gland cells secreting the fluid that is discharged upon a mucous epithelial surface or in connection with closed epithelial surfaces found in connection with the blood and the lymph cavities. Secretions are either external or internal, the external referring to secretions discharged upon a free epithelial surface like the skin or the mucous lining; the internal secretion is found in connection with the closed epithelial surfaces of such glands as the liver, pancreas, etc. This does not mean that other organs, even without epithelial surface, may not secrete substances in connection with the blood. For example, the muscles may give to the blood such substances as are analogous to secretions. In the case of external secretion it always takes place upon a free surface of epithelium resting upon a membranous basement. the other side of the membrane being freely supplied with blood capillaries and lymph spaces. The secretion always takes place in connection with the blood, the discharge taking place in the epithelial surface so as to communicate with the exterior. Of this kind is the membranous surface of the alimentary canal. Wherever we find the membrane pouched or formed into sacs with a definite bore we find the primary gland either tubular or sacular. In the case of the compound gland we find the complexity of the insolutions with branching side portions either in the common tubular or saccular form

according as the terminal parts end in the tubular or saccular form. In these compound glands it is only in the terminal parts that secretion takes place, these terminals being alveoli or acini, the communicating parts being called the ducts, the lining membrane of these ducts having no secretory action. The gland secretions are as different as the structures in which the secretion takes place. In general these secretions other than the reproductive secretions are fluid or semifluid, being composed of water, salts and other organic substances. The organic elements differ in the various glands repsenting the elements which are peculiar to the gland. being formed in connection with gland activity. In other cases the organic elements are found in the blood, the glands simply separating these elements from the blood so as to be eliminated, as the urea of urine. These last are the excretions of the body, excretion being the process of the elimination of waste matters from the body such as would be disadvantageous to the system if retained. Thus excretion does not refer to any secretion taken as a whole, some elements being derived from different secretions as in the case of urine of which urea and uric acid are formed in some of the organs, the water and salts being taken from the blood. Similarly, the bile represents an excretion carrying away some waste matters while it is also a secretion containing valuable elements in the digestive action. Excretion, therefore, represents the carrying off of the waste of the body organs or certain parts of some of the secretions which constitute the excretions.

No general theory of secretion can be formulated, because the formation of secretion varies in the different glands so that each gland has its own peculiar form of secretion. Formerly it was supposed by Physiologists that secretion was accomplished by filtration, diffusion and imbibition, the membrane beneath the epithelium being supposed to form with the epithelium, the membrane through which diffusion took place in connection with the blood and lymph. The differences in the secretions depends upon the structural difference and the chemical action of the membrane. In this case the epithelial cells were supposed to be inactive and the metabolism of the cells was not supposed to be of importance in connection with the secretion. In modern times, emphasis is laid upon the living membrane, the gland itself being used in the process of secretion; the epithelial cells being active in the secretory process. This is evident from the fact that on examination under the microscope the secretion is found to contain parts of cellular substances. In some cases the cells being broken down to form the secretion, as in the case of the sebaceous glands. In the case of the stomach glands there is an expulsion of part of the mucous from the cells to form the secretion.

In the mammary glands, the cell substance is broken up and in other glands the secretion of the substances take place in the cells in the form of granules which, when the fluid is passed through the cells from the blood or lymph becomer dissolved. The substance of the gland cells passes into the secretion in this way and represents the metabolic process of the cell substance. The variations in the secretions are easily explained on this basis as depending upon the metabolism of the different gland cells. In addition to this the existence of nerves connects with those gland cells, the stimulation of which produces secretion is a confirmatory proof of this theory of the cell activity.

Ludwig first pointed out that stimulation of the chorda tympani increased the secretion of the submaxillary gland. Similar nerve fibers have been found in connection with the sweat glands, stomach glands, pancreatic glands and the lachrymal glands. These secretory fibers are found to be of two kinds, one regulating the secretion of the organic and another the inorganic elements. By microscopic examination these two kinds of fibers are found to end around the cells in plexuses. indicating the direct connection of the fibers with the cells. Changes of temperature in the glands are also noticeable in connection with the formation of the secretion indicating the existence of metabolic processes, the heat changes, marking the activity of the glands. Although the granular structure is favorable to the process of osmosis, this does not seem sufficient to account for the secretion of salts and other substances. In this case the cells in connection with which are found two fibers, one regulating the production of the organic and the other the inorganic elements, play a very important part, as these two fibers terminate around the cells. How the action takes place it is impossible to state. It is sufficient to indicate the fact that some cell metabolism takes place under the influence of nerve impulses, conveyed to the cells by the nerve fibers. In the formation of water in connection with the secretions, it was formerly supposed that by diffusion and filtration, it was passed from the blood and the lymph. It was supposed that the greater blood pressure accounted for the osmosis, the water and salts in solution in the water, being the products of transudation. To this there is the objection that in the case of living membrane there is not a free diffusion, even when the pressure is greater on the one side of the membrane. The lung of a newly killed frog was found by Santessen, not to permit of the free filtration of liquid from its cavity, even under great pressure; whereas, the same lung when dead, freely filtered the fluid under the same pressure. In addition to this, the secretion in the gland does not increase with an increase of blood pressure, proportionate to the increase of pressure. While, therefore, these processes of filtration and osmosis take place in connection with the formation of the secretions, these physical processes seem to be only a part of the process associated with the formation of the secretion.

Heidenhain distinguished two kinds of glands, the mucous and the serous, the difference being made on the basis of the physiological structure of the glands, and also upon the nature of the secretion. The secretion of the serous glands is limpid, containing a large proportion of water together with a small quantity of albumin, salts and the ferments. The secretion of the mucous glands is viscous and thready, on account of the amount of mucin present in the fluid. The parotid gland in the human subject is an example of the serous gland and the submaxillary in the human subject with the sublingual the orbital and some of the mucous glands of the mouth and oesophagus are examples of the mucous gland. In serous glands the cells are small and abundantly filled with granular material. In the mucous glands the cells are larger and freer from granular matter. The small goblet cells in the intestinal epithelium are examples of the mucous cells. In the fresh glands the granules are not distinct. The use of chemical reagents will make them distinct although they are not so closely packed together as in the serous glands. In the submaxillary gland both kinds of cells are found although it is called a mucous gland because of the large proportion of mucin in the secretion. Similarly the parotid gland contains cells that are mucous in character. The distinction is more definite and well marked in distinguishing between two kinds of cells, the serous and the mucous. The epithelium is of the columnar type, in the midst of these cells, being found the mucous cells. Primarily also columnar they become changed chemically in the production of mucin. producing a swollen condition at the free end. This

A similar increase in organic matter takes place if the gland has been previously resting, but this very soon stops, the continued stimulation producing a decrease after this point rather than an increase in the solid matter. If the gland, however, has been continually working although the water and salts increase, the organic matter will not increase upon stimulation. These experiments led Heidenhain to distinguish between the production of water and salts and the production of organic matters, a distinction he has explained by his theory of the secretory and trophic fibers. According to this theory there are two sets of fibers to the salivary glands, the one regulating the water and salt supply called the secretory and the other producing organic matters in connection with cell metabolism, and hence, called trophic. In the case of the parotid gland, the sympathetic fibers are trophic or almost all trophic, while the cerebro-spinal fibers represent both the trophic and secretory. In the submaxillary gland, the sympathetic fibers are trophic or almost all trophic while the cerebro-spinal are secretory or prevailingly so. There may be variations in the individual fibers in the case of particular animals. This may be due to the fact that there is a combination of the two kinds of fibers in the one system. The trophic fibers are supposed to act by setting up metabolic processes in the cells resulting in the formation of certain substances like mucin. That these changes do take place has been demonstrated by microscopic examination. These processes represent the breaking up of complex matters and the formation of simpler substances found in the secretion. Side by side with the katabolism we find anabolic changes forming new materials from the blood supplies furnished to the cells, although the katabolic changes are more prominent, being under the influence of the trophic fibers. The action of the secretory fibers is obscure although it is supposed that the flow of water is regulated by the gland activity, this gland activity attracting to the gland cell the water from the blood, the water being absorbed during the resting condition of the gland from the membrane which collects its fluid, the lymph in turn being supplied from the blood. As the water in the cell increases there is a point reached when the equilibrium is established after which no more water is passed. By the action of the secretory fibers the process of filtration is materially assisted, the water passing from the cell into the lumen of the tubule. Ranvier has pointed out that during secretion there is the formation of minute vacua in the substance of the cell, these being filled with water. During the activity of the glands there are very marked changes in the cells both of the mucous and serous glands. In the parotid gland during rest the cells are large, solidly filled with granules, the nucleus being small.

After the stimulation of the sympathetics the cells become smaller, the granules more closely compacted, and the neuclei more regular and rounded, the granules being arranged in two layers, the outer and inner, the latter being more dense. By increased stimulation the granules are decreased and are collected around the margin, the increase of stimulation throwing out the substances from the cell and the cell becoming smaller in size. In this way the granules are utilized in the formation of organic matters. It is supposed that the ptyalin or that from which it is formed, is contained in the granules during the resting condition, the ptyalin formation taking place during activity. During activity these granules change and are removed from the cells and new substances are built up out of the matters derived from the blood and lymph, representing the nongranular matter. During the resting of the cell there is formed new granular matter. In the mucous cells we find during rest the cells large and clear with flat neuclei toward the cell base. During activity the neuclei are rounded and approach the center of the cell, the cells being smaller. By prolonged activity the cells become still smaller, some of them being broken up and their places being taken by the crescent cells lying underneath. In these mucous cells large numbers of granules appear from 100 to 200 in every cell, the granules being composed of mucin or something from which mucin is formed. As the secretion goes on these mucous cells like the serous cells become smaller, the granules being used in the formation of the secretion. There are thus two processes in the act of secretion, the process of water diffusion from the blood including salts and the production of certain constituents of the saliva in connection with cell metabolism.

These constituents when formed in the cells are washed out into the ducts by the water from the blood. If small quantities of atropin are injected into the blood or into the duct of the gland, the activity of the cerebro-spinal fibers, is suspended on account of the paralysis of the fiber endings in the cell. It does not seem to affect the cell as the stimulation of the sympathetics produces secretion. On the other hand, if pilocarpin is injected into the blood, or the gland ducts the secretory fiber endings stimulated and there is produced a continuous secretion. Nicotin seems to have a different effect, stopping the action of the secretory fibers by producing paralysis of the cells in the ganglia, through which the fibers pass to the gland cells. If the chorda tympani is divided after a few days, the secretion of the submaxillary glands begins slowly and continues slowly for some time until the gland becomes atrophied. This is called the paralytic secretion. If the chorda is divided on the one side there is a secretion on both sides, the secretion on the side opposite to the one divided, being called anti-paralytic by Langley. He explains the phenomena as due to the excitation of the secretion center in the medulla, being so largely increased as to produce by the excessively venous blood the continuous secretion.

Bradford, however, explains it more satisfactorily by saying that the anabolic fibers of the gland are inhibitory of the katabolism of the cells so that if these fibers are divided, the gland cell is handed over to the continuous action of the secretory fibers, producing a continuous secretion until the gland is atrophied. Normally salival flow is the result of stimulation of the sensory fibers, the glosso-pharyngeal and lingual nerves, of the mucous membrane of the tongue, the impulse thus arising being sent to the center and transmitted by the efferent fibers along the chorda tympani or the sympathetic system to the glands by reflex action. If the chorda is divided the reflex is cut off, even if the sympathetics are undivided. As the flow of saliva is a reflex action there would naturally be a reflex center associated with the flow, and it has been located in the medulla not far from the vaso-motor center. If the medulla is destroyed no salival flow can be produced by stimulation. The direct irritation of the medulla will produce a flow. This center may be stimulated through the vagi, the sciatic or the splanchnic nerves, as well as through the psychic centers as in the case of nausea, preceding vomiting when there is a flow of saliva. In the same way the center may be inhibited under the influence of the higher centers as in the case of emotion, fear or fright.

SECTION III. Pancreatic Secretion.

The pancreas in the human subject is found behind the stomach in the abdominal cavity. It is found to be a long narrow gland, its upper end being in contact with the duodenum, and its lower end resting upon the spleen. The main duct opens into the duodenum along with the bile duct below the pyloric orifice. Sometimes there is a small duct farther down. The pancreas is one of the compound tubular glands, the alveolar cells being serous, the outer part of the cell being composed of non-granular substances, the inner part toward the cavity being granular. In addition to the regular cells there are also a number of small and clear cells irregularly shaped, supposed by some to be imperfect secretory cells and by others a different kind of secretory cell taking part regularly in the secretory process. The tubular cavity of the cell is continuous with the capillaries which lie between the cells, the capillaries branching out into the cell substance. The pancreatic secretion is clear and alkaline in reaction. Its character depends on the time when it is taken and also on the animal. Its alkaline reaction is due to the presence of the sodium carbonate, varying from .2 to .5 per cent. The pancreatic secretion seems to depend somewhat on the stomach digestion, the beginning of the secretion being connected with the beginning of digestion and therefore a reflex action. There are distinct secretory fibers just as in the case of the salivary glands. The stimulation of either the sympathetic or the pneumogastric increases the pancreatic flow after a period of latent rest. The same distinction of the fibers is found in connection with the secretion, the secretory fibers predominating in the pneumogastric and the trophic fibers in the sympathetics. By the stimulation of the medulla the flow of pancreatic juice is increased, changing the contents of the organic portion. Some previous experiments give different results, probably on account of the changes in the blood supply, as the constriction of the blood vessels hinders the action of the secretory fibers. If the sympathetics are stimulated there is usually no effect upon the secretion because at the same time there is constriction of the vaso-constrictor fibers. If the sympathetic nerve has been previously cut so as to produce degeneration of the vaso-constrictors, the application of stimulation will produce, after a period of rest, a secretion of the pancreatic juice.

Heidenhain's theory of secretory and trophic fibers has been applied to the pancreas, the sympathetics containing the trophic fibers and the vagi the secretory fibers. It is difficult to explain the period of latent stimulation which is long, between the application of stimulation and the secretion of the fluid. It has been suggested that this is due to the presence of inhibitory fibers which check the action of the secretory fibers. The cell changes in the gland are very similar to those of the salivary glands. By subjecting the pancreas of the rabbit to microscopic examination the pancreas can be examined while alive, both active and inactive. During inactivity the cells become indistinct, each cell being filled with minute granules covering the nucleus and leaving exposed only a small zone next to the basement. When active the cells are smaller and more distinct, the granules being fewer in number. In the case of the fresh gland which has been inactive the cells are full of granular matter except at the base where there is a narrow zone non-granular. In the case of a pancreas that has been active the granular portion is much smaller and the non granular part much larger. The cell is found to be much smaller during activity, the granular matter being used up in connection with the secretion. When the secretion has been completed the cell returns to its normal resting condition, new granular matter being formed, the new granules filling up the whole cell except a small portion at the basal end. When the gland is not active the separate cells cannot be clearly distinguished from one another, the only distinction

in the gland being between the clear and dark zone. While active the cells of the gland become distinctly marked, the part of the organic matter of the secretion being formed in connection with the granular matter, the granules being formed inside the cell. This seems to imply that during rest the cell is forming by metabolism certain products out of its own substance, certain substances which fill the cell so that during secretion these are discharged from the cell and unite with the water and other substances to form the secretion. It is supposed that the pancreatic ferments are taken from the granules of the cells, the granules containing the zymogen from which the ferment is formed. If the gland is taken from a dog that has been fasting and the gland is prepared with glycerine there is almost no ferment found in it. If the gland is kept heated about 35° C and then after a day is prepared in glycerine the extract of glycerine will exhibit strong fermentive action. This indicates that the substance out of which the ferment is formed is contained in the granules, so that corresponding with the three ferments we have three ferment formers. The pancreatic flow is closely connected with the digestive action. As soon as the food enters the stomach there is a flow of the secretion which increases until it reaches its maximum about the second hour after a meal. Afterward it gradually diminishes until the fourth or fifth hour and then increases again until the 9th or 10th hour after which it gradually diminishes. These estimates have been made in connection with the dog and would require modification in application to the human subject, depending chiefly on the variation in the time of meals. In human beings and lower animals the beginning of the secretion seems to be almost simultaneous with the beginning of digestion in the stomach. This indicates that pancreatic secretion is aroused by the stimulation upon the mucous membrane of the stomach, the action taking place reflexly. In some animals it has been found that by the use of condiments like pepper, or mustard introduced into the stomach and intestine the pancreatic secretion is greatly increased. It has been found that acids have the same effect while alkalies have the opposite effect. The acidity of the gastric juice is probably the chief stimulant, the flow of the gastric juice originating the impulses that excite the pancreas. This action probably takes place by stimulation of the sensory fibers of the mucous membrane. The nerves of the pancreas come from the solar plexus of the splanchnic sympathetics, some of them coming primarily from the right vagus. If the medulla is stimulated the resting gland will secrete fluid indicating that it is a reflex action, and this takes place, even though the vagi are divided so that the efferent impulses must pass some other way than through the vagi. If the gland is active secretion will be arrested by the stimulation of the central end of the vagus. The same effect follows from the stimulation of the sciatic indicating the inhibition of the center in the medulla. It is claimed by some that even after cutting off all nerve connection the gland will continue to secrete but this has not been proved. Thus, the action of the pancreas during secretion is very much analogous to the action of the salival glands.

SECTION IV.--Gastric Secretion.

The gastric glands are simple tubular glands which possess no system of ducts such as are found in the compound glands. There is a large opening in each gland, the opening being lined with epithelium of the columnar type. The longer part is narrower and forms the secreting portion, being lined with cells of the cuboidal type. The pyloric glands differ from the fundic glands, having only one kind of secreting cell while the fundic glands have two kinds of cells. In the fundic glands the lining is of cylindrical epithelial cells which Heidenhain calls the principal cells. It is in these cells that pepsin is formed. There are also oval cells lying close to the basement membrane and not extending as far as the cavity of the gland. These are called marginal cells, sometimes oxyntic cells because of the formation of the acid of the gastric juice in these cells. These cells are spoken of as undeveloped cells of the principal type. It seems that they are cells of a peculiar kind, having a special function of their own. In these cells it is found that there exist often a number of nuclei, as many as five or six. In the cells are also found vacua which develop, after the beginning of digestion becoming larger, and then after becoming smaller gradually disappear. This seems to be connected with the formation of the secretion. The duct of the gastric gland is not continuous throughout the length of the gland, the central cavity sending off branch cavities to the marginal cells forming a meshwork around the cells. The principal cells have direct communication with the central cavity, the marginal cells being communicated with by a series of capillary branches. This indicates the fact that the marginal cells are distinct from the principal cells. In the secretion of the glands upon the mucous membrane we find the gland secretion mixed with mucin derived from the cells upon the surface of the mucous membrane. In addition to the mucous, the water and the salts, there is the hydrochloric acid and the ferments pepsin and rennin. According to Heidenhain the secretion of pepsin takes place in the pyloric end. The pyloric end was, by him, made in a seperate sac and bound to the abdominal walls so as to be separated from the rest of the stomach, so that the secretion of the pyloric end was obtained free from the secretion of any other part of the gland. This forms the negative proof which Heidenhain finds for the secretion of the hydrochloric acid in the marginal cells of the fundic glands, the pepsin being formed in the pyloric end where principal cells only are found. Some have denied this because the alkaline character of the solution found in the pyloric end they say represents an abnormal condition on account of the division of the vagus nerves, hence, it is claimed that the reaction of this part of the gland, like the other, is acid, normally. In the gastric glands the nerve connection is obscure. The stimulation of the vagi and the sympathetics gives no positive results and their division does not retard or arrest the secretion. In cases reported, the sight of food, in the case of starving animals, and in a case reported in which the complete closure of the œsophagus produced a flow of gastric juice, there is an indication that impulses are sent down from the higher centers. In the same case the chewing of food in the mouth, although no swallowing could take place produced a flow of secretion indicating the reflex stimulation in connection with the mucous membrane of the mouth. By making two fistulous openings, one in the upper part of the œsophagus and one in the stomach so that food masticated and passed to the œsophagus, passed out at the opening, the masticatory and insalivation processes produced the flow of gastric juice in the case of the use of animal food. After the division of the two vagi there is no longer any gastric secretion, indicating that by the passage of reflex impulses through the vagi, the first secretion was produced. In confirmation of this it was proved that stimulation of the vagi resulted in the increase of the gastric secretion after a long latent period. From this it is concluded that there are secretory fibers from the vagi to the glands of the stomach, these nerves receiving impulses reflexly from the stimulation of the sensory nerves of the mucous membrane of the mouth.

Heidenhain removed a portion of the fundus making it into a blind pouch,

attaching one end to the abdominal wall in order to form a fistula. The cut parts were stitched together so that the stomach remained continuous, the fundic pouch being entirely cut off from the alimentary canal. When food was digested there was found a secretion in this pouch, the secretion beginning shortly after the food entered the stomach and continuing until it passed through the stomach. By the swallowing of water a similar secretion took place although indigestible matters did not produce any such secretion. The secretion, therefore, depends upon the stimulation of the food and is limited to the parts where the stimulation takes place. Following this initial secretion there is a secondary secretion which takes place when absorption begins in the stomach. This secretion in the isolated pouch was found to belong to the secondary secretion, the stimulation arising in connection with the absorbed products of the food in the stomach, acting either upon the glands of the stomach or upon the intrinsic ganglionic centers in the stomach. These experiments have been repeated by recent physiologists, preserving the nerve connection intact with direct results.

By this means the effect of different kinds of food upon the secretion and its acidity have been studied. During inactivity the gastric mucous membrane is of a pale color not moistened, covered with mucous and in flapping folds. during activity it becomes red and moist, the folds disappearing, and fluid being found at the openings of the glands. If active secretion takes place the blood flow is rapid, the blood being arterial in color so that vascular dilatation accompanies the gastric secretion. As the food is brought into close contact with the mucous membrane, it is probable that the secretion takes place under the influence of local stimulation. This is proved by the application of stimulation to a particular part when the secretion takes place at that point. The secretion was found to begin almost immediately after the taking of food, increasing rapidly until it reaches the maximum about the second hour, after which the flow decreases. With the increase of the flow there is an increase of acidity followed by the decrease in the amount of the secretion. The action of digestion becomes very decided after the second hour. It has been found that the greatest secretion takes place in case of a mixed diet, especially if it consists largely of animal meat. A diet of wholesome bread produces a secretion that is of great digestive power. By the administration of acids, alkalies and neutral acids, no distinct variation in the secretion was noticeable, while the use of water indicated a decided increase in the gastric secretion. The most important stimulation of the gastric secretion occurred in connection with the peptones, producing a large secretion of the gastric juice. It is supposed that the water and peptones directly stimulate the sensory nerve fibers in the mucous membrane, reflexly affecting the secreting glands by the efferent fibers. Thus, the normal secretion takes place on the basis of nerve stimulation. The nerve supply to the stomach is found in the vagi and the splanchnics from the solar plexus. The anterior part of the vagus from the œsophagus is distributed to the smaller curvature, and the anterior part of the stomach, constituting a plexus. The posterior nerve is distributed in the posterior part of the stomach. The majority of the fibers pass to the solar plexus. These vagi branches are almost all non-medullated, only a few being medullated. From the solar plexus the nerve fibers pass with the cœliac artery from branches to the stomach. The fibers from the solar plexus and the stomach are non-medullated. These nerve fibers all lie beneath the peritoneum, passing inward with the arteries to form a plexus between the longitudinal and circular coats, and another plexus in the submucous coat. It is from this last plexus that the fibers pass to the mucous coat. During the secreting process, the cells, especially the principal cells, manifest great changes. Heidenhain took the glands from dogs that were fed once a day. During the inactivity of the cell he found it large and clear. During the active condition of the cells the principal and marginal cells increase in size, but that in the later digestive period the principal cells become smaller, while the marginal cells continue about the same size, or increase in size. There is a short period toward the close of digestion when the principal cells increase, after which they decrease gradually till they become normal again.

Langley found that the principal cells when inactive were filled with granular matter while during activity the granular matter is used up, first, being removed from the base of the cell, this being the first part to be filled with the non-granular matter. This granular matter represents an intermediate stage in the preparation of the ferments of the gastric secretion, representing therefore, the zymogen, preliminary to the formation of pepsin or the pepsinogen. The glands of Brunner are found at the beginning of the intestine close to the pyloric part similar to the stomach glands at the pyloric end. These intestinal glands have some branching tubules, the cells being identical with the cells of the pyloric glands. The secretion of these glands is small and is supposed to contain pepsin. In the small and large intestines, the Liberkuhn crypts are found similar in appearance to the gastric glands but different in the epithelial lining which is found to contain goblet and columnar cells, the former secreting mucin. It is questionable whether these glands form an independent secretion, the intestinal secretion being associated with these glands, the ferment being invertin. The cells of these crypts are different from the normal secreting cells, so that if their function is secreting they are a peculiar kind of cell. The secretion of the stomach glands, therefore depends upon the stimulation of the mucous membrane either by the food or by some artificial means such as a feather in connection with the mucous membrane, although in the last case, the secretion is very small. In the case of all the cells we have found in the salival pancreatic and gastric glands the same characteristics. The substance of the cells is actively producing part of the cell secretion, the elements assuming the form of granules. This may not represent all the matter stored in the cells. During the cell activity this matter is discharged from the cell in some way, whereas, new matter is formed in connection with the cell substance in order to prepare for still further secretion.

SECTION V. Hepatic Secretion.

The liver is a compound tubular gland. The secretory part of the liver is represented by hepatic cells, the ducts representing the channel along which the bile secretion is excreted from the gland. There are other changes taking place in connection with the liver in the formation of glycogen and urea but as these belong to metabolism and excretion proper they will be discussed later. In the liver, therefore, we have internal and external secretion. The liver is divided into lobules, these lobules consisting of hepatic cells arranged in columns extending outward from the center, the capillaries inside the lobule being so arranged that each one of the cells in these column of cells has blood supplied from the hepatic artery and the portal vein. In connection with the formation of external secretion the bile ducts are closely connected with the minute interlobular branches encircling the lobules. It is difficult to trace out the connection of the capillaries with the ducts of the lobules and the hepatic cells. Each of the hepatic cells has connection with the bile capillaries and also with the blood capillaries. the substance of the cell dividing these capillaries from one another. Recent experiments have proved that the

bile capillaries have direct connection with the cells by means of fine ducts. Much discussion has arisen in regard to the relation of the hepatic cells to the epithelial lining of the bile ducts and the question of the existence of a distinct wall in the bile capillaries. The majority believe that there is no distinct membranous wall in the bile capillaries, these representing simply the spaces between the cells, forming canals along which the bile passes. At the point where the capillaries unite with the ducts the hepatic cells unite with the epithelial lining of the ducts forming a continuous membrane. These hepatic cells are the secretory cells. Several Physiologists have traced nerve fibers to these cells, indicating that the cell activity is controlled by the nervous connection.

Some recent experiments have pointed out the termination of the nerve fibers between the cells without entering into the cell substance. The bile is a composite secretion of a reddish brown color in the human subject. In addition to the pigments, salts, acids and nucleo albumin there is a large proportion of CO_2, loosely combined with the secretion, indicating the great changes that take place in connection with the metabolic processes in the cells. The amount of bile secreted daily can be estimated by means of a canula establishing connection with the bile duct or the gall bladder. It is estimated from 700 to 800 CC daily, or 10 to 14 CC per kilogramme of body weight. The bile must be secreted continuously, the secretion being stored in the gall bladder so as to be thrown out into the duodenum as occasion requires in the digestive process. Its movement from the liver into the alimentary canal is not continuous but intermittent, the excretion taking place in jets like the flow of blood from an artery, this being due to the contractions of the muscular coatings of the large ducts. Thus, while the secretion is continuous the excretion is intermittent.

The secretory activity is closely connected with digestive action. In the case of dogs it has been observed that the secretion becomes much more rapid three or four hours after the beginning of the digestive process, a diminution taking place, followed by another increase toward the ninth or tenth hour. It is supposed that the relation between the digestive action and the secretion of bile depends upon reflex action, some believing that it depends upon the increase in the supply of blood to the liver. If bile is present in the blood it will stimulate the activity of the hepatic cells. From this some have concluded that by the absorption of substances from the bile in the intestine into the blood the secretion is increased. There seems to be a variation in the bile depending upon the nature of the food, the secretion being greatest where animal food is used and less when the diet consists largely of fats. The amount of the bile changes with the blood-flow through the liver. The blood is supplied from the portal vein and the hepatic artery, although the bile secretion continues even after shutting off one of these sources. The material used most abundantly supplied to the hepatic cells is carried to them by the portal vein, the amount and character of the bile depending upon the character and constituents of this blood. If the portal circulation is obstructed the secretion is diminished. By the stimulation of the spinal cord the abdominal viscera become constricted producing a diminution of the portal circulation The secretion is also diminished. If the spinal cord is divided, the bile flow is lessened on account of the paralysis of the vascular system. If the splanchnics are then divided the stimulation of the splanchnics produces a still further lessening of the secretion. If the splanchnics are divided without dividing the spinal cord it increases the bile flow. the dilatation of the abdominal vascular system increasing the portal circulation. These facts would seem to indicate that the bile secretion depends upon the blood pressure, and it is, therefore, a matter of filtration. Even if the pressure in the bile ducts exceeds the pressure of the portal circulation, the secretion continues. The quantity of the secretion, therefore, will depend upon the quantity of blood flowing through the portal circulation rather than upon the pressure. The actual secretion depending not so much on the amount of blood as on the amount of elements found in the portal circulation, as all these are brought from the alimentary canal in connection with digestion. In the formation of the bile there is no direct evidence of the existence of secretory fibers controlling the secretion because by stimulation the fibers to the liver, vaso motor action is stimulated. The nerve supply to the liver comes from the solar plexus through the hepatic plexus associated with the portal vein, the hepatic artery and the bile duct. The nerve supply to the solar plexus is the abdominal splanchnics and the terminal of the right vagus. From the left vagus there are also small branches. The most of the fibers are non medullated. It has been shown that there are special motor fibers to the ducts and the gall bladder. If the splanchnics are divided and stimulated peripherally, the bile ducts and gall bladder will contract, stimulation of the central end producing dilatation. If the central end of the vagus is stimulated, contraction of the gall bladder takes place inhibiting the opening of the bile duct into the duodenum. This would indicate that the efferent fibers are found in the vagus, the efferent running in the splanchnics through the semilunar plexus. Thus the secretion of bile takes place continuously in the hepatic cells, being ejected into the bile capillaries, the amount depending upon the amount and composition of the blood flowing through the liver, the actual formation taking place in connection with the activity of the cells. While digestion is going on the bile secretion increases. When the bile reaches the ducts it is ejected by the secretion of the new bile, and the contraction of the walls of the ducts. The storage takes place in the gall bladder from which it is ejected intermittently into the duodenum. On account of the vasomotor action in connection with the stomach and intestines there is a full supply of blood in the alimentary canal, this resulting in an increased flow of blood to the portal circulation. Some think there are also rhythmic pulsations in the portal vein resulting in the rapid driving of the blood to the liver and therefore assisting in the secretion.

SECTION VI.--The Kidney Secretion.

The kidney is a compound tubular gland which consists of a secreting part including the capsule, the tubules and the loops and a collecting part consisting of a straight tubular part. In the secreting part, the epithelial lining differs very much in different parts of it. The solid part consists of a cortical and medullary part, the medullary part consisting of conically shaped malpighian bodies, the apex of these bodies opening into the sinus. The cortical portion is of a bright crimson hue. Each Malpighian body consists of two parts, a blood vessel portion, the glomerulus and the capsule, a continuation and expansion of the tubule. The glomerulus consists of a small artery which divide into a number of capillaries, these uniting to form a vein. The entire area represents a peculiar structure so that the blood flow is very slow and the blood pressure high.

Enveloping these glomeruli is the capsule with two walls, the one close to the capillaries composed of flat epithelial cells so that between the blood vessels and the glomerular cavity there are two thin epithelial layers, that of the capillaries and the glomerular epithelium. In this way the filtration from the blood takes place freely. The epithelium of the convoluted tubule has cells of the cubordal or cylindrical type granular in appearance. These cells have im-

portant secreting action. The secretion of urine takes place in the cortical part from which it is carried by the medullary part to the sinus, from whence it passes through the ureter into the bladder. The kidneys are composed of a number of smaller glands closely bound together. The tubules pass almost straight through the medullary part but are very much convoluted in the cortical portion. Every minute tubule starts in the cortical part as a small sac surrounding the Malpighian bodies. This sac is narrow at the neck, and the tubule forming it is very tortuous, passing into the medullary part and forming loops. In the loop there is a descending and an ascending portion, the latter part close to the cortical portion being spiral and forming the intercalary part of the tube, then forming the straight collecting tube. These small collecting tubes unite together, passing to the papillary, forming the papillary ducts. The urine composition is very complex, containing as it does the final excretions of the body in connection with the various body metabolic processes. It is a yellowish secretion with a normal acid reaction due to the presence of the acid sodium and lime phosphate. Its specific gravity is 1016 to 1020. In connection with the secretion it is important to consider the water together with the inorganic substances, the sodium chloride, the sulphates, phosphates and CO_2 and the nitrogeneous products, urea and uric acid. The nerve connection is very complete, the nerve fibers being traced into the basement membrane with terminals between the cells. The blood vessels course freely in the interstitial connective tissues, the veins and arteries running freely through the medullary and cortical substance. The lymphatics are found in connection with the minute arteries and around the capsule, the vessels being accompanied by nerves, the nerve fibers passing through the basement membrane and terminating between the secretory cells.

Two theories are held in regard to the secretion in the kidneys. (1.) That of Ludwig, that the secretion takes place simply by diffusion and filtration, the water being filtered through from the blood in the glomeruli bearing along with it the urea and the inorganic salts. The dilution of this fluid takes place in the passage through the torturous tubes by the process of diffusion in connection with the lymph that freely surrounds these tubules. Recent experiments seem to point to the secretory action of the epithelial cells of the tubules furnishing materials to the secretion. (2.) The latter theory of Bowman and Heidenhain is that water and salts are originated in the glomeruli, while urea arises in connection with the epithelial cells in the tortuous tubes through which the fluid passes in its passage through the kidneys. The secretion thus takes place in connection with the glomerus and also the cells of the uriniferous tubules. It has been supposed that the water is produced by the process of filtration from the blood, although it is questionable if filtration is a correct term to use in speaking of the passage of water and other substances from the blood to the glomerulus into the tubular cavity. The secretion process, however, in the main consists of secretion in connection with the blood flow as in other secretion and also a peculiar secretion, as we will see, due to the peculiar flow through the kidneys. The amount of water secreted depends upon the volume of blood circulated, as well as upon the pressure of the blood.

Heidenhain believes that the epithelial cells of the glomeruli, are active in the process of water secretion. The formation of the water depends upon the physiological condition of these cells, the quantity of urine secreted depending more upon the quantity of blood circulating than upon the pressure of the blood. It seems that recent experiments indicate that the epithelial cells of the tubules take part in the formation of the nitrogenous elements of urea and kindred substances. If the medulla is divided and urea, urates or sodium acetate are injected into the blood, there is an abundant secretion. It is not accompanied necessarily by a rise in blood pressure. There is a distension of the kidney but the urine secretion is too great to be accounted for by any local increase in blood flow. These substances seem to excite the renal epithelial cells, producing a very abundant secretion in to the tubule cavity. It is accompanied by the vascular dilation but not sufficient to cause the secretion. This indicates the activity of the epithelial cells, indicating a difference between the glomerular secretion and the epithelial cell secretion of the tubules.

If the ureters are ligatured there are urate deposits found very abundantly in the kidneys, these deposits existing in the tubules and not in the Malpighian bodies. The uric acid is thrown out through the epithelial cells of the tubules. Heidenhain by injecting a strong solution of indigo. carmine (sodium sulphindigotate) into the circulation after the division of the spinal cord produced a rapid secretion. The kidneys were then taken out and a precepitate of indigo carmine produced by the injection of alcohol into the vessels. Heidenhain found that the granules were in the tubules and not in the Malpighian bodies. There is no stream through the tubules as the flow of urine is arrested; hence the pigment remains where it is thrown out of the cells. It did not pass through the gromeruli so that it must have been taken up and acted on by the tubular cells.

According to recent investigations definite changes are found to take place in the cells, the secreting matter collecting in the interior of the cells, being afterwards discharged into the cavity of the cells. In birds, for example, urates can be found in the cells of the tubules and none in the capsules. When inactive, the cells are small and granular, the cavity of the tube being wide and the cells towards the cavity exhibit striated processes. When the secretion of fluid takes place it exhibits a bright vesicular area around the neucleus, followed by an enlargement of the cell toward the cavity, as the cavity diminishes in size and the striation disappears. After the cells become enlarged the cavity disappears, the fluid being thrown out by filtration, the cells being ruptured in the ejection of the substances of the vesicules. The water and salt secretion takes place in connection with the glomerular epithelium. The question is, does it take place by simple filtration, or is the epithelium active? If the filtration process was simple the amount of the urine would depend upon the blood pressure in the glomerulus. The kidney is a very vascular organ favoring a rapid flow ot blood. The renal artery comes away from the abdominal aorta in which the blood pressure is very high. The renal vein passes directly into the vena cava where the blood pressure is very low. Between the beginning of the renal artery and the end of the renal vein, there is a great difference in the pressure, the blood flow depending upon the difference in pressure, a difference equivalent to that found in the entire lower extremities of the body. If the blood pressure rises in the aorta, the blood flow will be greater and, therefore, the pressure would be greater in the blood vessels of the gomerule and vice versa. Experiments have proved that if the arterial pressure is below 40 or 50 mm. the urine secretion is suspended or arrested. If the renal arteries are constricted, there is a diminution of the secretion accompanied by a fall of the blood pressure and a diminution of blood flow. Distension of the renal arteries increases the flow of urine and also the pressure in the glomerular capillaries and the amount of blood flowing through the vessels. It has been concluded that as the pressure of the blood and the amount of urine vary together, the urine secretion depends upon the filtration process of the water from the blood. The variation depends, however, not only upon the pressure but also upon the quantity of blood flowing through the glomeruli. Heidenhain believes that it is the quantity of blood that determines the amount of urine. The epithelial cells can readily secrete water and do not act simply in the filtration process, the water secretion depending upon the activity of the epithelial cells. If the renal veins are partially compressed the flow of urine becomes slower, or may be arrested entirely. By the compression of the veins the pressure would be raised in the glomerular vessels, and if the pressure theory is correct it would increase the flow of urine. If there is compression of the renal artery the secretion of urine is stopped for a considerable time after the removal of the pressure. This seems to indicate that the epithelial cells are actively engaged in the secretion of water. By the exciscion of the kidneys some experimenters have kept up the kidney activity, proving that the amount of the blood and the rapidity of the blood flow regulated the amount of the urine secretion. This indicates that the greater part of the water is secreted in connection with the living cells of the tubules, although there is also a secretion of water and salts at other parts of the tubule.

How does this epithelial cell activity take place? On the analogy of other glands it would seem that the chemical and physical properties of the cell substance account for this production of water. This activity seems to be promoted, especially by large quantity of blood flowing through the glomerula. The salts that are found in the blood may act as excitants of cell activity, the chief excitant being in all probability, the urea present in the blood and lymph. The urea elimination from the blood does not account for the urea of the urine, because there is less in the blood than in the urine. The urea passes from the blood by some selective process into the tubular cavity. There must be great activity in the cells as the matter is passed into the tubules, as rapidly as it is taken from the blood. The urea seems to act as a stimulant to cell activity. The secretion of the kidneys depends upon the quantity of blood passing through them, therefore, the blood flow is an important factor in secretion. The kidney is an organ ofgreat vascularity when it is active.

It is stated that by the use of diuretics there may be made to circulate through the kidneys a volume of blood equal to the weight of the organs. This would bring into the renal circulation an amount largely in excess of that in any other organ of the body. It is estimated that under these circumstances 5 to 6 per cent of all the blood leaving the left ventricle per minute enters into the kidneys. The blood supply is regulated in the kidneys by the vaso-motor action, this vaso-motor action being effective by acting through the arterial blood pressure. The kidney is furnished with a definite vaso-motor mechanism. By the use of Ray's Oncometer an adaption of the Plethys mograph the active influence of the vaso-motor system in the kidneys may be tested. It consists of a box shaped like the kidneys consisting of two parts, connected at the back by hinges and locked together in front. Inside the box membrane is fixed to each part so that olive oil may be placed between the membrane and the metal wall. This forms a soft cushion of oil upon which the kidneys press. The kidney with its nerve and blood connection is placed in one half and then the box is closed so that no exit remains except one for the olive oil which is in connection with the Oncognoph a measuring and recording instrument. As the kidney increases there is an out flow of the oil and every decrease in the kidneys results in a flow of oil, these changes being recorded by means of the recorder. The urine flow can be found out by means of the canula inserted in the ureter. The increased flow of urine is simultaneous with the enlargement of the kidney, that is, with an increased flow of blood, and a diminished urine flow accompanies kidney shrinkage, that is diminished blood flow. The increase in volume may be produced in connection with the enlargment of the cells, by the accumulation of lymph and the enlargement of the blood vessels, the latter being the most important element. In this way it has been shown that constrictor fibers act upon the blood vessels of the kidneys, these constrictor fibers coming from the constrictor region of the spinal cord in the lower thoracic region. In the dog it is said to be from the 6th dorsal as low down as the 3d or 4th lumbar mainly, however, from the 11th, 12th and 13th dorsal nerves, passing the sympathetics in connection with the splanchnic ganglia through the solar plexus and the renal plexus to the kidneys which they reach as nonmedulated fibers. If these nerves are stimulated there is contraction of the renal arteries, the kidneys decrease in size and the urine secretion is diminished, these being more marked in the case of stimulation of the 11th, 12th and 13th dorsal nerves and less marked in the higher roots. If these fibers are divided dilatation takes place in the arteries, the kidney is enlarged and the amount of blood flowing through it is increased and the urine secretion is also diminished. These nerves are stimulated reflexly and thus exert a continuous influence upon the kidney and its secretions. There are also dilator fibers to the kidneys which produce when stimulated dilatation of the arteries and an increase in the blood flow. These nerves come from the spinal cord by the anterior roots of the 11th, 12th and 13th spinal nerves. The vaso dilator fibers also exist in the higher roots and are accompanied when stimulated by dilatation of the vessels of the other abdominal organs leading to the general fall in the blood pressure counteracting the kidney dilatation. They are stimulated reflexly and thus act upon the secretion of the kidneys through the increased blood supply. In this way there is a direct nervous mechanism controlling the blood supply and therefore, controlling the secretion of the urine. This is the only direct influence of the nervous system upon the secretion. Aside from these local influences and influences affecting the general arterial pressure and flow will have a modifying effect upon the secretion. The kidney is very subject to influences due to chemical action, for example, injecting a small quantity of water into the blood produces kidney distension after a brief period of shrinkage. Urea injected into the blood produces more marked swelling. Similarly sodium chloride solutions and diuretics like sodium acetate. These changes take place even after separation from all nervous connection external to the kidneys. Increase in blood pressure associated with asphyxia or poisoning by strychnine tends to lessen the amount of blood flow through the kidney, and lessens the secretion. If, on the other hand, from any cause the skin vascular system is dilated the blood pressure is lowered and consequently the blood flow is diminished. Any change in the blood that will alter the relation of the blood pressure between the renal vein and artery will increase the blood flow unless this is changed by the contraction of the arteries. Any dilatation of the renal blood vessels on the other hand will increase the flow of blood unless by the fall of blood pressure the force of resistence becomes so strong as to prevent the flow of blood from being sufficiently rapid, and therefore it decreases the amount of blood flowing through the kidneys. With the increase in general blood pressure which implies a rise in the abdominal aorta there is a greater flow through the kidneys, if the renal arteries are not constricted. This may be caused by the heart pulsation and the respiratory movements.

If, however, the renal arteries are constricted as in cases of dyspnœa, the blood vessels are contracted, increasing the blood pressure but the renal vessels are also constricted so that less blood flows through the kidneys. Thus, a general rise in the blood pressure may be accompanied, either by an enlargement or a diminution of the kidney, and therefore, an increase or decrease in the blood flow. Similarly a fall in the blood pressure will lead to a lessening of the flow of blood in the renal vessels unless it is accompanied by dilatation of the renal vessels as in the case of division of the spinal cord below the medulla. We may conclude, therefore, in connection with these experiments that there are two processes in urine secretion. 1. Glomerular secretion. 2. Secretion in connection with the epithelium of the uriniferous tubules, both of these differing from ordinary secretion such as we find in the case of salivary gland secretion.

(1.) Glomerular secretion. By dilatation of the renal artery there is a more rapid blood flow through the glomeruli, and it exerts a greater pressure upon the walls of the glomeruli. We cannot at present increase the blood flow without increasing the blood pressure, but pressure may be increased without affecting the flow. If the blood is prevented from flowing out through the renal vein the pressure is increased in the glomeruli. This results in the diminution of the flow of urine instead of an increase. This proves that mere pressure does not produce the passage of water through the glomerular loop walls, and therefore, it is not a mere filtration process. All that passes through the loop walls is water and some soluble substances found in the blood, some say proteid while others say there is no proteid at all. In the case of the loop wall we find not only a membrane but also a layer of epithelial cells. The materials found in the urine must pass through these epithelial cells, the cells determining what shall pass through. In order to accomplish this there must be a rapid arterial blood flow assisted by a high pressure. In the epithelium is a condition of derangement as in the case of the cutting off of the blood supply to the glomeruli the uterine secretion will be arrested. On removing the obstruction the urine secretion begins and it will be found to be albuminous so that the albumin which does not usually pass through the epithelium passes through when the epithelium is abnormal. Thus the presence of albumin in the urine indicates an abnormal kidney condition, especially of the glomerular epithelium. This indicates the activity of the epithelium of the glomeruli as well as diffusion and filtration in producing the secretion.

(2.) Epithelium of the urinifureous tubules. The epithelial cells of the tubules are active in secretion. If the kidneys are extirpated, or if they are damaged there is an accumulation in the blood of urea. This indicates that urea is not formed by the epithelial cells from kreatin taken from the blood but that the epithelial cells have the power of selecting the urea and extracting it from the blood and then driving it into the cavity. We have no evidence of any process of urea formation in the kidney. If urea is injected into the blood there is no increase in the amount of urea in the urine, but an increase in the urine secretion and flow. In the case of hippuric acid found in the human urine it is formed by the combination of benzoic acid and glycin. If a kidney is removed from the body and the circulation is kept up and then benzoic acid and glycin are added to the blood before it enters the kidney. Hippuric acid will appear in the blood as it leaves the kidney. If the kidney is allowed to die this will not take place so that it is a living process. The cells of the kidneys are supposed to have the power of selecting these substances from the blood and forming hippuric acid. The action of the cells seems to be in accordance with the general kidney function that of secretion in preparation for the discharge of the waste matters from the body, in some cases combining these substances so as to excrete them in a peculiar form. There is a great variation in the substances of urine, especially as between water and solids. It is often advantageous to the system to discharge a large amount of water. This may take place when the cutaneous discharge is arrested or suspended as in the case of constriction by cold of the cutaneous channels of excretion. The same is true in cases of a large proportion of fluid taken in the form of drink. The amount of water passes to the blood increasing the dilatation of the renal vessels and, therefore, promoting activity of the glomeruli. The substances found in the water may also affect the secreting activity of the glomeruli promoting the secretion. Similar effects are noticed in connection with the emotions increasing the urine secretion. In the case of hysterical urine there is a discharge of urine excessively, the water being in large excess of all the other constituents. In this case the impulses pass down from the brain through the vaso-motors, producing dilatation of the renal blood vessels and thus producing a flow of urine.

SECTION 7. Epidermal gland secretions.

The sebaceous glands are either simple or compound and are found over the superficial surfaces of the body, sometimes associated with hairs and sometimes not, as in the case of the lips and prepuce. In connection with hairs, the short duct connects with the hair follicle so that the secretion passes out in connection with the hair. The cells of these glands are found arranged in layers, those lying nearest the cavity being filled with fat and being destroyed in the formation of the secretion. By the formation of new cells around the basement membrane the secretion becomes continuous. The secretion or sebum is an oily substance containing fat and soap, cholesterin and albumin, inorganic salts and broken down epithelial cells, the secretion varying in character in the different glands in which its formation takes place. The prepuce secretion is called smegma preputii, that of the auditory meatus blended with the sweat glands forms cerumen. On the skin of a new born child there is a sebaceous secretion called vernix caseosa. This sebum physiologically furnishes a protection to the hair and the epidermis. It provides lubrication to the skin and also to the hair, preventing the hair from becoming hard and brittle. In addition it furnishes a protection against the rapid loss of heat from the animal body by evaporation, maintaining normally the epidermal character of the skin.

SWEAT GLANDS.

Sweat is a secretion in connection with the sweat glands of the outer surfaces of the body. These glands are found over all the external surface, particularly in the palms of the hands and the soles of the feet. They are estimated to number between two and three million glands over all the body. In the human subject they are small tubular glands, the end parts of which contain the secretory cells, these cells being knotted upon one another to enlarge the surface of the sweat glands. In the large ducts we find a coating of muscles that plays an important part in the excretion of the sweat from the gland. In the secretory part the cells are columnar in type, consisting of a cytoplasm that is granular. The secretion varies with changes of temperature and also with the mental and physical conditions of the subject. In the average subject the normal secretion varies from 700 to 900 grams daily. It is difficult to determine the composition of the sweat secretion as it is mixed with the secretion of the sebaceous glands. It is a very limpid secretion varying from 1,003 to 1,005 specific gravity with an alkaline reaction. The first secretion of the sweat is normally acid as it is mixed with the sebaceous secretion. It contains in addition to water, sodium chloride, alkaline sulphates and phosphates, urea, uric acid, kreatinin, and albumin with some of the oxy-acids and ethereal sulphates if the sweating is very profuse. If the kidneys are deranged there is

usually a large proportion of urea in the sweat, the crystals being found clearly in the deposits. The sweat nerves are believed to be in the human subject secretory fibers, the secretion being the direct result of the nervous action upon the sweat gland cells. The terminal fibers are brought into close contact with these epithelial cells so that as the result of stimulation of various kinds the production of sweat may take place. An increased external temperature affects the sweat glands through the nervous system, the temperature affecting the sensory cutaneous nerves and reflexly producing stimulation of the fibers of the sweat glands. It is not known where these sweat gland centers are, although the great center is supposed to be located in the medulla. The sweat nerves were first discovered by Goltz, in connection with the cat. The sweat glands in the cat are found in the pads of the feet and it is easy to show the existence of sweat fibers. If the sciatic nerve is strongly stimulated at the peripheral end there may be produced sweat upon the pads of the feet. If stimulation is applied nearer the peripheral end then the same result may be produced. This secretion is characteristically limpid with an alkaline reaction.

Langley has worked out these secretory sweat fibers in the cat. In the case of the hind feet they leave the spinal cord in the 12th thoracic, 1st, 2nd, and 3rd lumbar nerves, join the sympathetics, leaving it as non-medullated fibers in the rami communicantes from the 6th lumbar to the 2nd sacral ganglia and then unite with the sciatic plexus. In the case of the front feet he found the nerves passing from the spinal cord in the 4th to the 10th dorsal nerves, passing thence to the sympathetics and to the stellatum ganglion, from whence they pass as non-medullated fibers to communicate with the brachial plexus. These nerves seem to act directly and not indirectly through the blood. Even after the blood flow has been cut off from the leg, the stimulation of the sciatic still produces the sweat secretion. This is found in the human subject when the palor of the countenance accompanies profuse sweating, the fevered condition of the skin accompanying the absence of sweat. These experiments seem to indicate that the sweat fibers are real secretory nerves directly acting upon the gland cells and producing the sweat secretion. This is confirmed by the histological facts that give evidence of direct nerves to the glands, the fibers ending in the cells. These sweat fibers may be excited in many ways as by heat and muscular exercise. In the case of heat there is a direct action upon the nerve fibers. If the nerves going to the leg be cut and exposure is made to intense heat there is no result produced in regard to the secretion of sweat. The heat seems to act on the sensory heat nerves, producing the stimulation reflexly. The same effect is noticeable in connection with pilocarpin which stimulates the nerve fibers producing secretion, while atropin paralyzes the fibers and prevents secretion. There must be, therefore, some center or centers in the central nervous system through which sweat regulation takes place. It has been taken for granted that there is great sweat center in the medulla which forms the basis of the sweat activity. This seems to be negatived by the fact that when the medulla is divided from the spinal cord the action of certain stimuli still produces the sweat secretion. This has led to the opinion of some that ther are sweat centers in the spinal cord but nothing definite has been formulated upon this subject. Thus we find that the sweat is furnished both by the sebaceous and the sweat glands, the sweat secretion depending upon the character of these two secretions. There is little variation in the sebaceous glands; hence when the sweat is profuse the sebaceous glands have little influence and where it is scarce then the sebaceous glands have considerable effect upon it. Hence, normally the sweat glands may be considered as the sweat secreting glands. There is a slight fluid transudation in connection with the skin and it is small as compared with the fluid gland secretion because it is greatest where these glands are most abundant. The sebaceous glands do not vary much in their secretion so that the sweat glands are left to do the most of the work. There is a close connection between sweat secretion and the blood supply.

In the horse in which the cervical sympathetic was divided there was found an increased blood supply on the side divided and also increased sweating. In the case of the cutaneous vessels if constricted the secretion is lessened, if dilated the secretion is increased. It is this that aids in regulating animal heat If the atmosphere is hot there is a dilatation of the cutaneous, vessels an increased perspiration and a greater loss of heat by evaporation which helps to cool the body. If the surrounding air is cold the cutaneous vessels are constricted, sweat is scarce and there is much less evaporation resulting in the loss of heat. As we have seen this is controlled by the secretory sweat fibers. The profuse perspiration resulting in the case of the death agony and in the case of mental excitement as well as the anæmic sweats results from direct nervous action.

THE MAMMARY GLANDS.

These glands are like the sweat glands. They are compound glands with acinous structure consisting of small divisions of cells richly stored with albumin and fat. The mammary glands are formed like the sweat glands by a growth inwards of the Mi pighian bodies of the epidermis. They consist of ducts that branch off terminating in the secretory cells. The cells differ as they are active during the condition of pregnancy or inactive in other conditions. In the active glands the cell consists of a basement membrane lined by a single layer of epithelial cells. These cells differ at different periods and even at the same period. When the cell is empty of the substance it is cuboidal, the cell consisting chiefly of a cavity. The cell consists of granular cell substance with a nucleus. When filled the gland presents columnar cells jutting out irregularly into the cavity and reducing the size of the cavity. Instead of a single nucleus there are usually two or three nuclei, nearer to the base being one and the others nearer to the margin. At times the marginal part of the cell seems separated from the base and at these times parts of the cell may be found in the cell cavity, within the cell are found oil droplets and granules, some in the substance and others projecting from the cavity. In passing to the empty condition the cells change considerably in size and shape. In the case of the resting gland where the animal has never borne any offspring the cells are much smaller in size being a solid cylindrical mass. They grow very slowly and the metabolic processes send out substances into the blood. When pregnancy occurs the cells grow rapidly, new cells being developed. When the birth of the offspring approaches the fatty cells break off from the colostral fluid, the broken cells being the colostral corpuscles. The cells of which they are composed consist of single epithelial layers. They are said to have originated from primitive skin glands without any mamma, these smaller primitive glands being united together to form larger ones, an opening arising in the skin localized in the nipple. In the human subject they are normally two in number and are localized in the thoracic area. The mammary ducts are not united into a single duct but are grouped together as separate glands representing 15 or 20 separate glands with openings centered in the nipple. These granular cells are imperfectly formed unless during pregnancy when the cells multiply by a kind of cell genesis, during the period of lactation providing for an accumulation of the milk. The fluid secretion consists of a plasma,

and a great number of globules which float in the plasma. These globlets consist of the milk fat, especially the neutral fats, olein, palmitin and stearin together with traces of the fatty acids, lecithin, cholesterin and the milk pigment. The milk plasma consists of water holding in solution proteids, carbohydrates and salts. Among the proteid we find casein, lacto-albumin and lacto-globulin in much smaller quantities. The principal carbohydrate is the lactose. A nucleo-proteid is also found the nucleo-glyco-proteid. Traces of urea and kreatin are also found in the plasma together with citrate of calcium, lecithin and cholesterin. This secretion takes place in connection with the epithelial cells as there are matters found in connection with the milk not found in the blood or lymph. During the resting condition the gland manifests in its vesicles a condition in which flattened or cuboidal cells appear with a single nucleus and with a few fat granules. After the lactation commences these cells enlarge the nucleus divides and each cell is found with two nuclei. The fatty matter and the granules pass through a process of change, the cell itself being elongated and these being discharged from the cell end, the discharge and the disintegrated part of the cell being passed into the secretion. Part of this forms the fat globules in the milk and part of it forms the constituent elements of the secretory fluid. Sometimes only a part of the cell becomes disintegrated. Sometimes the entire cell is dissolved. When the entire cell is dissolved the place is supplied by the process of karyokinesis. In the first milk secreted there are found peculiar colostral granules. Heidenhain accounts for these by certain rounded epithelial cells which in the process of development develop fat cells that are thrown into the gland. Others regard them as due to the dissolution of cells of connective tissue which degenerate and are discharged in the gland during its earliest stages of activity. The milk secretion varies from 1,028 to 1,035 in its specific gravity and if quite fresh is alkaline in its reaction. As soon as it ceases to be fresh it becomes acid. In milk we find various substances.

(1.) PROTEIDS. The chief proteids are casein and lacto-albumin. Under the influence of rennin the casein becomes curdled and insoluble. If milk is mixed with neutral salts or diluted with acetic acid and then a stream of carbonic acid passed through it, precipitation takes place, the lacto-albumin being discovered by means of heating. In the process of curdling casein is divided up into tyrein and an albumose called lacto-protein. The lacto-albumin does not coagulate in the natural milk being hindered by the alkaline character of the milk.

(2.) FATS. In addition to olein, palmitin and stearin we find other fats furnished by the combination of butyric acid and glycerine. There is great variation in the kind of fats present in milk. The milk represents fat in an emulsified condition.

(3.) LACTOSE. This represents the milk sugar which under the influence of a ferment may become lactic acid.

(4.) SALTS. The chief salts are lime phosphates, potassium and sodium chlorides and magnesium phosphates. There are also small traces of iron and sulpho-cyanide. The milk secretion at the commencement of lactation is called colostrum. It differs from normal milk in containing a large number of colostral corpuseles very much like the leucocytes, some of them being regularly formed cells and others disintegrated parts of cells some of which are characterized by amœboid movements. In the colostrum there is also a large proportion of globulin as well as a quantity of albumin. In the disintegration of the alveoli we find the colostral granules. The mammary glands are found in the male and female at birth about the same condition. After birth the glands become active and discharge a milky fluid after which they remain dormant in the female till puberty when they begin to develop, while in the male they remain dormant except in abnormal conditions. Thus, the mammary secretion while in common with other glands possessing certain characteristics of gland activity have certain peculiar features. In the case of the mammary gland the activity is more definite. As the empty cells become filled, or refilled with secretion the cells grow. The substance of the cells increases in size and by becoming longer it is thrust out into the cell cavity. The nucleus divides and the new nuclei become imbedded in the cell substanre. While the cell substance actually deposits within it the elements of the milk secretion. Following this there is an excretion of the secretion. The fat globules are first ejected from the cell substance and then the cell division takes place, the parts of the cell and the nuclei separating and lying in the cavity of the cells where they pass through certain changes. Thus the elements consist of the cell substance in part and in part of the elements secreted in the cell substance. Thus the nuclein of milk probably arises from the broken up nuclei. In this case the secretion is a manifestation of cell activity. It is from the blood that the elements are extracted but the changes take place in the cell itself. The formation of fat takes place in the alveoli, this formation taking place even from proteids when insufficient fat may be present in the food, the cell making this transformation and not simply collecting it from the blood. Similarly the casein is formed in the cell as it cannot be gathered from the blood. Even the albumin is different from the serum-albumin of blood being the lacto-albumin. The lactose, or milk sugar, is also formed in the cell as it is not found anywhere else in the body. Some think that the glycogen like body found in the cells is the preliminary substance in the formation of lactose. The gland is active, therefore, in the secretion of the mammary fluid. It is supposed that mammary secretion is under the control of the nervous system. It has been found that strong psychic influences such as emotions have destroyed or suspended the milk secretion although this is disputed by some. The external spermatic by some of its branches furnishes vaso-motor fibers to the glandular blood vessels, indirectly influencing the milk secretion by the influence exerted upon the blood flow in the gland. The division of the inferior branch has been found to increase the secretion while stimulation results in the diminution of the secretion. It has been found that the stimulation of the sensory fibers in the case of goats lessens the milk secretion. If the mammary glands are severed from all connection with the central nervous system, then the stimulation of any of the afferent fibers has no effect upon the secretion. If the external spermatic is divided on the two sides then the secretion is lessened, whereas, if it is divided on one side only, there is no change in the secretion. In these cases the diminution does not take place at once but comes on gradually. Even after the extrinsic nerves are entirely cut off the secretion continues to take place and the gland becomes enlarged as usual with lessened secretion. The mammary gland, therefore, must be subject to the control of the central nervous system, but whether this takes place through the vaso-motor fibers or through secretory fibers cannot be settled. It seems to be automatic in action, the relation between the mammary glands and the uterus depending upon the blood rather than upon the nervous connection. Recent experiments indicate the close connection of the cells with the secretory fibers but whether this will be confirmed is a matter as yet unsettled. The secretory cells are not formed until after the first pregnancy the secretion beginning only after parturition, although the cells increase in number during pregnancy. The first secretion is that of colostral fluid differing from the milk in the character of the cells which have wandered about and have passed through a stage of decomposition. After a few days the colostrum gives place to milk which is secreted in the cells and collected in the galactophoric duct, the secretion continuing until the duct is filled when the formation of the secretion is inhibited. As soon as the ducts are emptied a new secretion begins. This process of emptying forms the stimulation necessary to the secretion in the cells. As soon as this stimulation ceases to act the secretion itself ceases.

SECTION VIII. The Ductless Glands.

The internal secretions are formed within the gland, and are passed from the gland, either into the blood or the lymph. In every activetissue in connection with its metabolism there is a waste which is carried into the blood and the lymph. The internal secretions, however, refer to those secretions which take place in definite glandular organs which are used either by the organs or for the metabolism of the entire body. This was first discussed in connection with the testis and pancreas. These secretions are found in connection with what have been called the ductless glands. As yet our knowledge of these glands ond their secretions is very incomplete. In connection with the liver there is a substance formed in connection with the hepatic cells which passes into the blood that falls under this head, namely, urea. It is the principal nitrogenous waste of the proteid metabolism. It passes off from the body through the kidneys, but it is not formed in these glands. It seems to be formed in the liver in connection with certain substances that arise out of the proteid metabolism, these substances being carried to the liver where urea is formed. The urea is secreted in the liver and from thence it is given off to the blood. The hepatic cells perform this metabolism for the entire organism, the liver seems to assist in the utilization of the iron arising in connection with disintegrated corpuscles. There is also formed in connection with the liver cell glycogen in connection with the sugars and proteids brought to the liver by the protal circulation. This stored up substance is eliminated by in connection with general metabolism, in connection with which we will discuss it.

In connection with the pancreas it has been found that there is also an internal secretion. The pancreas has been removed without any immediate fatal results. After the removal of the pancreas it was found that the urine possessed in large excess of saccharine matter. In this case it has been found that this condition of glycosuria follows even when the carbohydrates are taken out of the food. The urine increases in quantity accompanied by a thirsty condition. If these conditions continue the animal becomes weakened and emaciated death ensuing in two or three weeks. Experiments have been made in animals which seem to prove that the partial removal of the pancreas prevents the accumulation of sugar in the urine; 1-4 or 1-5 of the pancreas being sufficient to prevent this accumulation of sugar in the urine. From this it is concluded that there is a secretion in the pancreas which either consumes the sugar, that is produced in the organs of the body, or else prevents the sugar from being eliminated from the liver and the body tissues. It is claimed that recent experiments prove that in cases of diabetes there is post mortem proof of this disease being connected with certain variations in the pancreas.

The thyroid bodies are glands found in the human subject joined together in front of the trachea by a narrow band. It is a double lobed sacculum, the two lobes being united together without any duct. These consist of masses of alveoli connected together in connective tissues which send septa into the interior, separating the alveoli from one another by oval spaces. In connection with these septa we find numerous blood vessels springing from the superior and inferior thyroid arteries whose branches surround the alveoli in networks of capillaries. From these the veins collect the blood, forming plexuses in the organ surface ending in the inferior and middle thyroid veins. Around these septa we find also a large number of lymphatic vessels arranged in plexuses, the nervous connection springs chiefly from the cervical sympathetics, from the middle and lower cervical ganglia. They consist of a large number of closed cells of varying sizes, each cell being covered with epithelium and filled with a slimy fluid, this fluid is a gluish liquid called colloid, the secretion of the cells of the thyroid, first secreted in the cells then thrown out into the cavity of the body. It is believed by some that this fluid is finally discharged into the lymphatic system. This colloid is a somewhat gliary and solid substance, this glairy fluid consisting of mucin, although some think it is not pure mucin. In addition to this the alveoli contain serum-albumin and globulin. The thyroid extractives are found to contain kreatin, xanthin and lactic acid. From the presence of the mucin it has been suggested that the thyroids have something to do with the formation and distribution of mucin. In some animals there are found accessory thyroids found in different parts of the upper portion of the body which in case of the removal of the the thyroids, discharge the functions of the thyroid bodies. If the thyroids are much enlarged we find a goitre condition and also the cretinous condition which is associated with a form of idiocy. The extirpation of the thyroids in animals is attended with fatal results, death being preceeded by muscular twitchings which sometimes pass into spasms and also by a condition of malnutrition almost amounting to emaciation, These muscular conditions depend upon the nervous system as the division of the motor nerves frees the muscles from such action.

It is supposed that this nervous action arises from the changes in the brain and spinal cord. In the lower animals fatal results have not always followed thyroidectomy, perhaps chiefly because of the existence of accessory thyroids, which on the removal of the thyroid, take their place. Where the thyroids are removed the red corpuscles are diminished in numder and the white increase very much, salivary glands are enlarged, the parotid gland secreting mucin and blood. Where fatal results follow, they are more rapid in the case of young than in older animals. In the human subject the fatal results are much slower in appearing, being accompanied by anemic conditions, muscular debility, loss of mental capacity, and characteristic subcutaneous swelling. If a small part of the thyroids is left then the fatal results do not follow, in the lower animals it is claimed that fatal results may be obviated by the grafting of a part of the gland in some position under the skin or in some other portion of the body easy of access to the blood. According to Horsley there are three stages following the removal of the thyroids. (1) The neurotic period during which muscle twitchings and nervous excitement are accompanied by a dyspnoeic condition. (2) The mucin period during which myxœdema is developed, mucin being deposited in the tissues, and, (3) the atrophic stage during which the muscles become atrophied. The thyroids, therefore, have an important function in connection with the body metabolism. According to some their function is to absorb and take out of the blood certain noxious substances which would interfere with the metabolic processes. The removal of these bodies produces a condition, it is said, of auto-toxication, these toxic substances accumulating in the blood. In proof of this it is claimed that the blood and urine of animals from which the thyroids are removed has

a peculiar toxic influence, if injected into other animals. These results are denied by some physiologists. If the thyroids become enlarged we find the exophthalmic goitre with protruding eyeballs. 2. According to others, the thyroids secrete a fluid which is a true internal secretion and when discharged exercises a potent influence upon metabolism, especially the metabolism of the nervous system. In proof of this it is claimed that to inject thyroidal extracts produces good results. This substance formed in the gland reaches the blood through the lymbhatic system after it has been secreted within the cells of the gland. This last fact proves that there is a true internal secretion, and if this is so, then it must have an important bearing of some kind upon metabolism. Some have been successful in extracting from the gland a substance called thyroidin which is found to contain a large quantity of iodine, often as much as ten per cent of the dry substance and which is found to have good results in cases of goitre and myxœdema. This proves that the thyroid produces an iodine compound and it has been found that this compound consists of a combination with proteids. Recent experiments have indicated the presence of a number of such compounds all of which are found to be valuable in the body metabolism. The larger part seems combined with thyroid-albumin, the smaller part being combined with a thyroid-globulin. These substances when given to animals upon whom thyroid-ectomy has been performed have good results.

The suprarenal capsules or adrenal bodies form another of these ductless glands. Surrounding the bodies are the connective tissue capsules, septa passing inward from the capsule forming a frame-work of cells of different structure. The substance of the cells is of a yellowish color, sometimes containing yellow oil globlets with a distinctly marked round nucleus. In the cortical part the cells are of different kinds, some columnar. In the medullary part the cells are different, the substances of the cells being clear and transparent and distinguished from the cortical part by the abundance of blood vessels and nerves. The nerves are chiefly medulated nerve fibers from the solar and renal plexuses, the phrenics and vagi nerves entering suprarenal body and forming plexuses' the fibers ending in the cortical and the medullary parts. The substances found in the suprarenals consist of proteids and also some substances containing peculiar color reactions. The histological character of the cells suggests that certain processes take place in the cells in connection with the pigment metabolism of the body. As the nerve connection is very complete there seems to be a close connection with the nervous system. The complete extirpation of these bodies is followed by death, the fatal effect resulting more quickly than in the case of the removal of the thyroids. Following the removal we find muscular and mental exhaustion and a marked blood depression. These results correspond with the conditions in connection with Addison's disease, in which case there is a suprarenal disturbance. Addison first noticed that diseased conditions of the suprarenals involved a bronzing of the skin, accompanied by giddiness, vomiting and dyspnea. In cases of Addison's disease it has been found that adrenal extracts have a good effect. It has been claimed that death results from the removal of the suprarenals on account of the presence in the body of a toxic substance it produces auto-toxication. Others have claimed that the suprarenals discharge an important function in connection with the muscles secreting a secretion that has a very definite action upon the muscular system. Solutions of the medullary part of the gland have been found to exert an influence upon the muscles of the heart, the blood vessels and the skeletal muscles. In the case of the heart it was found that on the division of the pneumogastrics the heart's action became stronger, whereas, muscular contraction became more protracted, the blood pressure being greatly increased. From this it is concluded that the secretion of the suprarenals is constantly of value to the muscles and other tissues of the body acting as a stimulant.

In regard to the pituitary body it is claimed that fatal results follow its complete extirpation and that it follows the same course as death from thyroid ectomy indicating that they perform the same function or similar functions in the body metabolism.

In connection with the reproductive glands Brown-Sequard has made a number of experiments. Fresh testine injected into the blood has a remarkable tonic influence on the nervous system, especially in connection with the spinal centers, in cases of neurasthenia and general debility. This is said to be due to the presence of a substance in the secretion which passes into the blood. A substance called spermin extracted from the secretion by Brown-Sequard has been found to materially assist the metabolic processes, not only having a tonic influence, but also diminishing body and mental fatigue and increasing the efficiency of the neuro-muscular mechanism of the body, preventing muscular and nervous exhaustion and also diminishing the sensations associated with exhaustion.

The spleen is an organ whose functions as yet are not distinctly understood. The spleen may be removed without any fatal results, the noticable effects being that after its removal there is an enlargement of the lymphatic glands and an increase in the bone marrow together with an increase in the activity of the medulla. It has been found that one result of the removal of the spleen is the decrease in the number of the red corpuscles and the amount of the haemoglobin. From this it has been infered that the spleen has something to do in the formation of the red corpuscles. The chief known facts about the spleen are in regard to its movements the spleen is known to increase in size during digestion attaining its maximum about five hours after a meal, remaining for a time enlarged and afterwards returning to its normal position. This is possibly due to the action of vaso-dilator fibers and the relaxation of muscular contractions in connection with the capsule and trabeculae, the relaxation of tonic contractions being the most important factor. By the use of the plethysmograph, a spleen curve can be made. The variations in the volume corresponding with the respiratory movements. This enlargement is noticable in pyrexia accompanying fevers, especially ague, in some cases the enlargement becoming permanent.

The spleen also manifests slow rhythmic contractions and expansions and alterations in size, corresponding with the variations of blood pressure and coincident with the respiratory movements. These alterations are determined by the contractions and relaxations of the muscular fibers of the spleen, and also the change in calibre of the arteries, both of these changes being regulated by the nervous system. The expansion of the spleen does not take place according to the blood pressure for there is a resistance on the part of the muscles which retards expansion. The spleen is a muscular organ expanding to receive a large volume of blood and contracting to send it on to the liver. In the spleen there is a special local circulation, the spleen being abundantly supplied with nerves, which upon stimulation cause the decrease of the size of the spleen. These nerve fibers are found in the splanchnics containing both inhibitory and acceleratory fibers. The splenic circulation is carried on largely by means of these contractions. These contractions being quite regular in their movements. If the central end of s me of the sensory nerves is stimulated the spleen contracts; simularly if the peripheral ends of both vagi and

both splanchnics are stimulated it produces a quick contraction of the spleen. If both the vagi and splanchnics are divided and a sensory nerve is stimulated contraction of the spleen takes place. What the object of these rhythmic movements is as yet unknown but they seem to depend upon the small ganglia which acts as automatic centers. These contractions and relaxations vary considerably, depending upon the blood supply determined by the needs of the organ and upon the needs of the liver which are largely guided by the blood changes in the spleen. In the spleen there is found a large proportion of iron together with fats, fatty acids, cholesterin, nitrogenous extractives, xanthin, uric acid, etc. The uric acid is always present. The existence of these substances seems to indicate that certain active changes take place in the spleen in connection with the metabolic processes of the body. During foetal life it is certainly a producer of red blood corpuscles Uric acid is said to be produced in the spleen. Uric acid is always present in the spleen but whether it is formed in the spleen is not as yet settled. If so, then it must be formed in the spleen as well as in the lymphoid tissue generally, but nothing definate can be stated as the removal of the spleen may take place without any serious interferance with the economy.

SECTION IX.—2. Excretion.

We have seen how the food passess through the digestive process and by absorption, passes through the blood to the different tissues of the body. In passing through the blood and tissues, certain changes take place, the excess of fluid being carried as waste into the lymphatic system and through the lymph into the blood. The various food elements, proteids, fats, carbohydrates, salts and water become changed, the proteids, fats and carbohydrates into urea, CO_2, aqueous vapor, (H_2O), the proteids producing nitrogen. From the proteids also are found sulphur and phosphorous which becomes changed by oxidation into the sulphates and phosphates being excreted along with the salts. These waste substances that find their way into the blood are not only excess but they represent dangerous elements if continuously accumolated in the blood. These substances that are eliminated are called excretions. Generally speaking, these waste elements consists of urea, CO_2, salts and water. These waste matters are eliminated through five different channels, the lungs, the intestines, the liver, the skin, and kidneys. As we saw in connection with respiration the lungs excrete CO_2 and also a quantity of aqueous vapor. In connection with the intestines we find then in the form of faeces, the undigested parts of food and the matter secreted in the intestines are excreted as faecal matters There remain to be considered, the two main excretory organs, the skin and the kidneys.

(1.)—THE SKIN.

It is concerned physiologically with the functions of sensation, protection, respiration and also excretion. It presents a sensory surface between the internal substances and the organs of the body and the external world. It has a variety of nerve fibers distributed over its surface that give rise to various reflex actions that keep the body in adaptation to its surroundings. It also has an important part to play in connection with animal heat and body temperature. The skin sonsists of two layers, the deep layer of connective tissue called the corium or dermis, and the superficial layer of epithelium called the epidermis. In connection with the skin we find two kinds of glands, the nails and hair, developed in connection with the epidermis. The corium consists in its upper surfaces of furrowed and cross furrowed areas forming either rounded or grooved shaped areas, the rounded areas appearing on the surface of the skin and the furrows on the palms of the hands. Between the furrows are found the papillae varying in size and number in different parts of the body, being largest in the palms of the hands and the soles of the feet and also most numerous. This corium consists of connective tissue interlaced with elastic fibers. The mesh work of tissues differing in the different layers, two of which are important, the papillary and the reticular, the latter or deeper layer presenting numbers of fat cells underneath these being the subcutaneous layer in which fat cells are abundant. The subcutaneous layer of tissue passes into the muscle fascia or bone periosteum. The epidermis consists of tesselated epithelium with at least two strata, the deep or soft stratum called the Malpighian or mucous stratum and the dense or corny stratum. Both strata consists of epithelial cells. In the mucous stratum being cylindrical with a long nucleus, those above being round or flattened cells. In the corny stratum are found polyginal cells flattened without any nucleus, these being formed from the hitherto developed mucous layer cells. The pigment of the skin is found in the deeper cells of the muscous stratum. In thick epidermal regions as in the hand and feet, there is a middle layer lying between the deep and the dense layer called stratum lucidum. Connected with the skin, are hair consisting of the shaft, that part above the skin, the radipili the part passing into the skin, sunk in the folicle and the bulb at the end of the root with a tubular recess filled with tissue called the papillae. The sebaceous glands open into the folicule.

SECTION X.—Sweat and Sebaceous Excretion.

In connection with the integument we find two glands. (a) The sudoriferous or sweat gland. These were first discovered by Malpighi. These are tubular glands, ball shaped, at the end, being the secreting part and situated in the subcutaneous tissue. The long straight duct passes with a slight winding course through the corium between the papillae running through the horny epidermis and opening on the surface by a round pore. These glands are found all over the body except on the glans penis and on the inner surface of the preputium penis being found most abundant in the palms of the hands and the soles of the feet. There are estimated to be as many as 2,500 to the square inch. Krause estimates that there are two million, five hundred thousand sweat glands over the body. The secretion of these glands is an oily fluid which lubricates the skin, normally during the resting condition. Under the influence of nervous stimulation, the watery liquid known as perspiration, is exuded.

(b). The sebaceous glands are simple or compound racemose glands. They are found in the corium and consist of a short duct opening into or in connection with tubes that open into the hair follicles. The secretion is a fatty matter mingled with the remnants of broken up cells. These glands are found all over the body except on the palms of the hands and the soles of the feet, some of these glands not being connected with hair follicles as on the lips, the labiaminora, the glans penis and the preputium penis known as Tyson's glands. In the negro races, these glands are found very large and numerous, sometimes being developed deep into the subcutaneous tissue. The subcutaneous arteries arise from vessels in the underlying fascia running out to the surface. They consist of three capillaries, the deeper lying in the fatty subcutaneous tissue, the middle forming a plexuses around the sweat glands and the most superficial forming the terminals of the artery, furnishing branches to the papilla, the hair follicles and the sebaceous glands in the papillary stratum.

In the papillary stratum arise the veins in connection with the papilla, the hair follicles and the sebaceous glands, the small vein branches etering close to the arteries and receiving branches from the sweat glands and passing into the fatty subcutaneous tissue. The lymphatics consist of two net works, the one lying in the deeper subcutaneous tissue with wide meshes and the other in the papillary stratum with very narrow meshes, the branching lymphatics arising around the hair follicles and the glands. The nerves are very abundant in the palms of the hands and the soles of the feet, having their terminals in the subcutaneous tissue and also in the touch corpuscle cells. The horny layer of the epidermis acts as a surface of protection and also as a barrier against absorption of poisonous substances. Each of the epidermal structures represents a development in connection with the excretions from the blood, each of these structures having its own constitution and independent existance, growing and maturing and then being replaced by others, which grow in the same way. These epiderminal structures are connected with the protection of the body aiding sensitiveness, warmth, etc. A limited quantity of water may be absorbed through the skin. Other substances particularly if mixed with fatty or oily substances especially in connection with mechanical rubbing, pass through the skin into the subcutaneous lymphatics. The epidermis is a medium through which the nerves of ordinaary sensation receive stimulation, and it may be that the deep cells of the stratum mucosin are to be regarded as the terminal organs of these nerves, the actual termination of the nerve fibers in the cells have not yet been enough definately made out. To a slight extent, respiration takes place through the skin, about 10 grams of O being absorbed and about the same amount of CO_2 being given off in the course of 24 hours, but the chief function of the skin is that with its glands, it presents a large surface through which excretion takes place. The chief substance excreted through the skin is water, with a comparatively small quantity of salts and a small quantity of CO_2. In the human subject the perspiration takes place largely on the forehead, on the palms of the hands and the soles of the feet, and the axillæ.

(a) SWEAT. The sweat yielded by the sudoriferous glands is a colorless, watery fluid transparent with the peculiarly saline taste and a characteristic odor varying in the different parts of the body. The sweat in the human subject is acid in reaction, although it is alkaline when very abundant. If a part of the skin is well washed, the sweat collected afterwards from the skin is alkaline. It is concluded from this that the pure sweat is alkaline, but that when mixed with sebum secretion it becomes acid. This acidity is due to the sebaic acids arising from decomposition of the sebaceous matter found in connection with the sweat glands. The specific gravity is about 1.004. On microscopic examination there are found oil globlets and crystals and sometimes some epithelial epidermic cells. Normally perspiration contains 97.5 to 99 per cent of water, and from 1 to 2.5 per cent solids. About two thirds of the solid matter consists of organic matters and one-third of inorganic substances in the form of salts, sodium chloride constituting the larger proportion, from 0.2 to 0.3 per cent, and small quantities of other inorganic salts, there are also found phosphates and traces of iron oxide, some traces of urea have been found representing proteid decomposition, but this normally is decomposed, giving rise to ammonium salts. It has been proved that where muscular activity is great the amount of nitrogenous waste eliminated from the skin may be considerable, amounting to .8 grams. Under ordinary circumstances, however, the amount of urea eliminated is small. Small quantities of the volatile fatty acids are present, giving rise to the sweat odor. Lactic acid is not present in a normal condition.

There are also found the neutral fats, cholesterine and small traces of albumin, various fatty acids such as buteric and acetic acid with caproic and caprylic acid giving rise to the odor. In pathological conditions sweat has been found to contain blood, urea and albumin in large quantities, sugar, uric acid, lactic acid and bile also in large quantities. The amount of sweat varies in different animals. Anything that assists the blood to supply the skin, tends to assist sweat secretion, and if the watery evaporation is greater from the glands than normal the surface of the skin is covered over with a profuse perspiration. Secretion of sweat is produced by exercise, profuse drinking of water, hot baths, high temperature, and friction applied to the surface of the skin. Morphine and atropin diminish or stop the flow of sweat, whereas muscarin. strychnine, nicotine and camphor increases the sweat flow. Mental conditions of excitement, either of excessive joy, anger or grief increases the secretion of sweat. There is a sympathy between the two excretory organs so that if the action of the kidneys is partially arrested as in certain abnormal conditions, the skin will discharge the excretory function more generally. It is estimated that about 900 C.C. of water is discharged by the skin in 24 hours in a normal adult or about 100th part of the body weight. This represents the second channel through which water is excreted from the body. It is very much less in proportion than that excreted by the kidneys. It seems to be important not so much from the standpoint of water excretion from the body as in connection with the loss of animal heat, or its preservation. The more sweat is evaporated, the greater is the heat loss. The first sweat secreted is more rich in fatty acids and salts with less inorganic salts, the reverse being true when perspiration becomes free, then the secretion becomes alkaline. Free perspiration lessens the flow of urine and at least diminishes the quantity of urea found in the urine. Iodine, alcohol and odoriferous elements may be discharged through the skin. The sweat secretion is dependent upon the blood pressure in the minute capillaries, the development of the gland cells and the nerve supply to these cells. After the secretion takes place the excretion is aided by the contraction of the smooth muscular fibers found between the cells and the membrana propria. Perspiration is more profuse on the right side than on the left side. The innervation of the sweat glands depends upon the vaso-motor nerves, the dilators and constrictors, and the trophic or secretory fibers. Perspiration will not be produced by the simple effusion of blood to the surface of the skin. Pallor may be found along with profuse perspiration, in this case the vaso-constrictors and the secretory fibers are active. There is no doubt that special secretory fibers are in existence. If the sciatic nerve in the cat is cut and stimulation is applied to the peripheral end perspiration will be found freely in connection with the foot pads. In the case of the cat perspiration in the hind feet depends upon nervous impulses conveyed along the sciatic nerve fibers. A cat whose sciatic nerve was divided on one side when placed in a hot room was found to perspire freely in the three feet while the foot in which the sciatic nerve was divided did not sweat at all. These secretory fibers in the sciatic nerves originate from the spinal cord from the anterior roots in the spinal nerves, from the ninth to the thirteenth dorsal vertebra. Some have located in this spinal area a spinal sweat center. The secretory nerves of the front limbs in the cat are found in the median and ulnar nerves arising from the spinal cord in the lower cervical region. The secretory fibers of the head and neck have been found in the cervical sympathetic, in the facial nerve and the fifth cranial arising from a brain center, possibly one of the cerebral centers as the mental states of excitement, emotion and pain produce influences affecting the sweat glands of the face and neck.

The stimulation of the facial nerve has been found to produce perspiration on the cutaneous region supplied by this nerve and also on the opposite side. The same is true of the median nerve. This seems to indicate reflex action in connection with the sweat centers. In what way this takes place is as yet unknown. If the perspiration is not very profuse and if the atmosphere around is dry, the watery fluid in the sweat passes off quickly as vapor, this vaporous element being called insensible perspirations. If, on the other hand, perspiration is profuse or if the atmosphere is moist the sweat freely flows over the surface of the skin and it is called sensible perspiration. The proportion of these two will depend on the secretion in connection with temperature and the motion of the surrounding air. When the air is dry and hot and the air in coutact with the body is rapidly renewed, the sensible perspiration is greater and a greater amount becomes insensibly evaporated. If the air is cool and moist there is a large amount left on the skin as sensible perspiration. Often we seem to perspire freely, when really there is but an increase in the sensible perspiration. The secretion may increase in a hot, dry air. The condition of the body also determines the amount of perspiration given off, for example, the quantity and kind of the food, the amount of fluid taken, the exercises of the body and the activity of the kidneys. If the skin surface becomes covered with solid substances, the skin will be coated so as to prevent the free action of the sweat, the openings into the ducts being closed. This constitutes one of the fundamental reasons why baths should be regularly taken by persons desiring to maintain normal health so as to keep the pores of the body open and to permit the free and active exercise of the sweat glands.

(b.) THE EXCRETION OF THE SEBACEOUS GLANDS. The substance secreted is of an oily character, semi fluid and of a characteristic odor. The fatty substances are formed by the epithelial cells of the glands, the sebaceous secretion consists of about 31 per cent of water, 61 percent of albuminous matter and broken down cell substances, 5 per cent of fatty matter and soaps including olein, palmatin and sodium palmitate with 1 to 1.5 per cent inorganic salts including the chlorides and phosphates. Its chief function seems to be in connection with the hair keeping the hair soft and flexible. It has also a function in connection with the skin, lubricating the skin and preventing the loss of water and also hindering the absorption, of aqueous substances through the skin. This includes the wax formed in connection with the ears and the secretion of the eyelids. The earwax is said to contain fat cells and cholesterine crystals together with a bitter substance not yet named. The amount of oily matter secreted varies among animals according to the species and even among individuals being largest among the negroes.

(c.) GASEOUS EXCRETION. The skin from the standpoin of respiration is concerned in the exchange of gases. The capillary vessels in the outer layer of the corium contain O and CO_2 and as the epidermis is the only separation between the gases and the atmosphere the exchange takes place upon the bases of the lose of diffusion the CO_2 being given off and the O being taken in to unite with the hæmoglobin. Aqueous vapor, H_2O, is also excreted through the skin when the surrounding air is not freely filled with such vapor. In the case of a frog whose lungs have been taken out respiration continues for some time, O being taken in and CO_2 eliminated, the frog being able to breathe without lungs, the respiration being carried on by the skin. In the human subject this respiration is limited on account of the thickness of the skin. By the enclosure of the human body in a gas tight chamber it has been found that by shutting out the respiratory gases the quantity of CO_2 given off in a day amounts to from 6 to 10 grams, similiarly from 6 to 10 grams of O have been absorbed by the skin in a day in the case of the human subject. This large amount of CO_2 does not necessarily come from the blood but may arise in connection with sweat decomposition and the O may be similiarly absorbed and used up in the oxidation process in connection with the sweat. It is estimated that CO_2 is given off by the skin to the extent of 1-150 and O taken in to the extent of 1-140 of that given off and taken in in connection with the lungs. The amount of aqueous vapor excreted cannot be estimated as it cannot be collected free from the sweat. This indicates that the exchadge by the secretory process of the skin is small as compared with the amount of gas required in respiration. If a rabbit is covered over with gelatin so as to prevent absorption of O or water and an exhalation of CO_2 and water, the rabbit will soon die. This death is not due to the suspension of cutaneous respiration as it is small compared with that of the lungs. These symptons seems to indicate poisoning accomopanied by a large loss of heat indicated by the fall of temperature If the warmth be preserved by the use of cotton so as to prevent the heat from being rapidly lost life may be prolonged. The skin also absorbs.

Cases have been recorded in which by emersion in water the body has increased in weight, this gain being due to the embibing of water by the skin. If the epidermis is removed absorption takes place rapidly but some have questioned whether such absorption is possible if the skin remains intact. It seems that there can be no reason why water and soluble substances should not pass through the intact skin. There is evidence that even solid substances may pass through the skin as solid particles rubbed into the skin if in a fatty medium become quickly absorbed in the lymphatics.

The formation of sweat is influenced by the same circumstances that influence the formation of other excretions, namely: (1) the supply of blood; (2) the nervous impulses; (3) the activity of the grandular epithelium. Hence, where cutaneous vessels are dilated, as, when the surrounded atmosphere is warm the excretion of the skin is increased while under opposite conditions the perspiration is very scanty in amount. The effect of nervous influences independently of the blood supply to the sweat glands upon the formation of sweat has, as in the case of submaxillary gland been demonstrated by experiments upon the lower animals. The phenomena of increased sweat under excitement, emotion, etc., is a well known example of these influences in connection with the higher centers. Simularly the cold sweats of phthisis in which pathaological condition there is not an excessive but a defective blood supply to the cutaneous vessels, form examples of the influence of body conditions upon body perspirations.

SECTION XI. (2) *The Kidneys.*

The kidney consists of a cortical and medullary part, the medullary part being formed into the pyramids of Malpighi conical shaped masses whose apices open into the sinus. The cortical portion is soft and of a dark color. The secretion takes place largely in the cortical part after which it passes through the medullary part into the sinus from which it passes into the pelvic cavity of the ureter and thence into the bladder. In the kidney we find a large number of tubular glands closely connected. The tubes (tubuli uriniferi) being very tortuous in the cortical portion and straight in the medullary portion. Each of the tubules originate in a small sac constricted at the neck encompassing Malpighian bodies in the cortex, the tube in convoluted form running into the medullary part forming a loop and returning to the vortex constituting the Henle loop, consisting of a descending and ascending portion. The ascending

portion becomes spiral and forms the inter-calary tube and then straightens out into the collecting tube. These collecting tubes as they pass to the medullary part unite together forming larger tubes which become papillary ducts in the papillæ. These minute tubules vary in size at different points of the path, the smaller tubules passing into the inter-callary ducts and finally into the wide collecting tubes. These tubes lie in the midst of loose masses of interstitial connecting tissue in the midst of which the minute blood vessels are found. The Malpighian corpuscle forms a plexus of blood vessels, known as the glomerulus encompassed by the expanded section of the urinifierous tubule called Bowman's capsule. This capsule consists of two portions, the internal covering the glomerulus and the external consisting of polygonal cells passing to the neck and forming the convuluted tube wall. The renal artery branches into the renal substance passing through the medullary part and passing up to thebounding line between the medulla and the cortex forming a series of plexuses with the convex parts towards the cortex. Out of these convex arches arise the interlobular arteries which branch off into the lobules each glomerulus receiving one branch which is divided so as to form afferent vessels with capillaries branching off into the interlobular efferent veins. These minute veins anastomose freely with the veins in the cortex, running quite close to the interlobular arteries. The arteriæ rectæarising from the arterial arches supply the medullary portion of the kidney, the medullary veins running in spiral form around the papillary ducts and opening into the venous arch at the bounding line between the medulla and the cortex. The renal lymphatics are found in connection with the capsules and the minute arteries in the renal substance, nerves accompanying the minute vessels, but with connections and terminations as yet unknown.

SECTION XII. *Urine Composition.*

The kidneys are functionally the organs through which the urine is secreted and drained off from the blood. Through them the main part of the nitrogenous waste of the body with a considerable quantity of water, some salts and CO_2 are excreted. The sold matters of the excretions of the body are excreted chiefly through the urine, only a small quantity passing through the skin and almost none through the lungs. Thus, all the substances are practically excreted through the urine except the fæces, these substances vary considerably in quantity and in composition.

The normal urine is a clear yellowish, slightly phosphorescent fluid with a peculiar odor and a saline taste. It is acid in reaction, the acidity being due, not to a free acid but to the presence of an acid salt, phosphate of sodium, the degree of acidity depends upon the diet, being said to be in inverse proportion to the acid secretion in the stomach. Thus, it varies with the kind of food. After taking a meal, the urine may be neutral or alkaline increasing after digestion in the stomach ends. In carnivorous animals it is acid and in herbivorous, alkaline, if living on vegetables but if starving or living on animal diet then it is acid. When the food is animal there is more acid production than can be neutralized. When the food is vegetable there is carbonate formation sufficiently great to neutralize the acids. With a vegetable diet the proportion of alkaline salts excreted in the urine is increased and that fluid becomes less acid, neutral, or even alkaline in reaction When the gastric juice is being secreted as when food is taken into the stomach the acidity of the urine is decreased. As digestion becomes more complete the urine becomes again distinctly acid. On exposure to the air for a time urine becomes more markedly acid, as fresh acid is formed by fermentation and urates or uric acid may be deposited, but subsequently the reaction changes to alkaline, the urea combining with elements of water to form carbonates of ammonia under the influence of micro organisms or organized ferments. These do not normally appear till the urine is discharged. Sometimes abnormally, however, fermentation takes place in the bladder, micro organisms being introduced from the air or an unorganized ferment bein formed inside. A deposit is also thrown down, the phosphates being precipitated partly as phosphates of lime, partly as the triple phosphates of magnesium, and urate of ammonia. The urine temperature is normally about 39° C after standing for some time there is a mucous deposit representing mucous corpuscles and sometimes flattened epithelial cells. Later this deposit will yield uric acid crystals, and still later the acid urate of sodium. If kept in a clean vessel and in the cool the acidity continues for some time. Later the acidity lessens slowly and then it becomes neutral and later alkaline, fermentation setting in on account of the presence in it from the air of the microco-cus ureæ. Microscopic examination revealing the presence of bacteria. If urine is preserved in a clean vessel and then boiled and caresully sealed it will keep for a considerable time. Under the action of the micro oaganisms urea is converted into carbonate of ammonia, a deposit being thrown down consisting of the triple phosphate, lime phosphate and ammonia urate. Urine may be alkaline if the alkalies are present if acetates, citrates, phosphates are found in the food.

The mean specific gravity is 1020, varying from 1015 to 1025. The color of the urine varies both in health, and disease. It may be pale, colorless or dark color. In diabetes it is usually very pale. It may be milk colored on account of the presence of chyle; dark red from the presence of a pigment or blood or greenish from the presence of bile. It may also be a bluish color due to the presence of indigo from indican. The normal variation in color depends upon the varying quantities of the pigment, urobilin which is the same as bilirubin taken from the alimentary canal. In order to find out the urine composition the urine must be collecte for a day and then subjected to analysis. This must be done in order to have a normal urine as it is subject to great change during a day. The amount of urine secreted by a normal male is about 1,800 to 2,000 CC, and an adult female from 1,400 to 1,600 CC. Sometimes it is necessary to estimate the amount of certain elements found in the urine by the volumetric method. Certain reactions are used, the solutions used being of definitely known strength, the weight of the substance being determined by calculation. This method is explained in urinalysis.

The urine consists of a great number of substances varying in their nature. Some being excreted just as taken in the food, others being the result of certain changes which the food has undergone in the alimentary canal, the tissues, and the kidneys. These constituents are:

(1.) WATER.—The solid matter in the urine consists of about 4 per cent. The solid matter varies with the specific gravity, every degree in the urinometer representing about 2.33 of solid matter per thousand. Water passes out of the body through the lungs, the skin and the kidneys. The amount excreted through the skin and kidneys being in inverse ratio to each other, that is when a great quantity is lost through the skin a very small quantity passes through the kidneys. The large proportion of water eliminated from the body is through the kidneys, the blood continually loosing water in this way.

(2) INORGANIC SALTS.—These salts exist mostly in their natural condition. These consist of chlorides, phosphates, and sulphates of the alkalies and alkaline earths. They rise partly from the salts taken in food and partly from the metabolic changes in the body chiefly in connection with the proteids.

Sodium chloride is the most abundant, amounting to about 1 per cent in normal conditions derived chiefly from salt taken in food. Hydrochloric acid is united with sodium, a normal adult excreting about 20 grams of sodium chloride. The amount depends on the food and also upon the normal or abnormal conditions of the body. In inflamation, as the crisis is reached, the amount is increased. Chloride of calcium, chloride of potassium, phosphate of lime, and chloride of magnesium together with sulphates are also found in small quantities. Phosphoric acid in the urine is united with the alkalies and the alkaline earths. Of this phosphoric acid about 2 to 3 grams are eliminated daily by a normal adult. The phosphates arise chiefly from phosphates of the food and the destruction of tissues containing phosphorous. The sulphuric acid in the urine is united with potassium and sodium constituting sulphates and also in union with the phenol and indol-oxyl sulphates of potassium, the sulphates being combined chiefly with organic substances, About two grams of sulphuric acid are eliminated daily by healthy adults. Carbonic acid is found in urine, as carbonate of sodium or combined with magnesia and calcium, In this case if a few drops of nitric acid is added, the urine will seath, this effervescence rising from the presence of CO_2. Lime is found in the urine almost entirely in union with phosphoric acid and oxalic acid, the amount varying within small proportions. Ammonia is found in the urine in nitrogenous form, yielding ammonia, the amount depending on the food, being larger in the mixed diet than in a vegetable diet. Magnesium, in the phosphate form, iron, and nitric acid exists in very small quantities in the urine.

(3) GASES.—These gases consist of CO_2 about 17 volumes per cent, N about one volume per cent and O about .1 volume per cent, although the O is present only in very minutes traces. Carbonic acid is found loosely combined with the acid phosphate of soda.

(4) PIGMENTS. Urine is always colored. McMunn claims that urobilin is always present in urine normally, although small in quantities. The pigments of the urine are not very satisfactorily known. This is increased by the fact that chromogens exists in the urine, that is the substances giving rise to pigments by oxidation: the urine pigments are at least two in number, urobilin and indigo from indican. The exact nature of the yellow coloring matter is uncertain. The urobilin does not give the yellow color to normal urine. Urobilin or hydro-biliruben which is formed from biliruben is sometimes present. In the intestines, part of the bile pigments is converted to hydro-biliruben which is absorbed and eliminated by the kidneys as urobilin. There is also indican or indoloxyl, sulphates of potassium which is believed to be produced in the alimentary canal and which on oxidation, yields various indigo pigments. On decomposition indican produces leucin and indigo, both blue and red. Indigo blue may be obtained from normal urine in small quantities. Uro-haematin is found in urine of rheumatic cases and in Addison's disease. Skatoloxyl, sulphate of potassium, uro chrome and uro melanin may also be found in small quantites in urine but these are not normally present as pigments.

(5) NITROGENOUS ELEMENTS —Aside from the special nitrogenous substances introduced along with the food the principle nitrogenous elements are urea from two to three percent and uric acid about .05 per cent. Small quantities of substances related to urea are also found. Kreatinin, hypoxanthin, hyppuric acid, oxaluric acid and sulphocyanides. These nitrogenous matters result from changes in the proteid substances and allied substances like gelatin in connection with the body metabolism.

(6) ALBUMIN.—Is is claimed that normal urine always contains albumin.

This, however, is not accepted, by all. There are found, however, ferments in the urine. If a large amount of alcohol is mixed with urine, there is thrown down, a precipitated, containing phosphates and several substances, in small quantities. The ferments are found to be amylolytic and proteolytic if the ferments are entangled in fibirin by washing out, ferments may be secured that will convert starch into sugar and if hydrochloric acid is added the pepsin will be found. From this it has been concluded that some of the alimentary ferments escape into the urine.

(7) NON-NITROGENOUS ELEMENTS.—Small quantities of various acids are found. Oxalic acid appears as the oxolate of lime when rhubarb, apples, tomatoes, etc., are used as food and in small quantities with any kind of diet. Lactic acid, butyric acid, formic acid, acetic acid and it is also said glucose in minute quantities are present normally in the urine. The amount of these various substances found in the urine vary considerably in different individuals and in different periods of life.

ABNORMAL URINE COMPOSITION.

There are some substances found in the urine under abnormal conditions the exact nature of which and the means of discovering them being discussed in urinalysis. Among these we find serum-albumin, and serum-globulin, haemi-albumoses, peptones, pepsin, haemoglobin and fibrin, the latter being identified in its fibrillar form by the microscope. In addition to these albuminous substances, sugar, bile pigments, bile salts, mucin, epithelium from the bladder or kidneys, or the urinary passages, pus cells and red blood corpuscles may be found. Corpuscles may be detected by the use of the microscope. In addition to these, there are found at times, casts consisting of cylinders of epithelial cells or fibrinous casts, formed out of matter in the lumen of the tubules. The urine may be milky on account of the chylous matter in the form of globules present in it. This is common in very warm climates and said to be due to parasites in the blood. Various substances such as carbolic acid, salicylic acid, iodine, bromine, etc., may be found in the urine. There are various kinds of urinary deposits, the exact nature of which is detected by the use of the microscope.

(1) These are found in connection with the urine when acid, for example, uric acid, found either free or in the form of urates. These urates are the most common form of the urinary deposit, forming a heavy precipitate when the urine is cold. The chief urates are those of sodium, potassium, and ammonia. In addition to these we find phosphates, crystals of oxalate, lime, tyrosin and leucin.

(2) Certain deposites are found in connection with the urine when alkaline, such as the triple phosphates always found in the urine when ammoniacal, lime phosphates, acid urate of ammonia, which is always found in alkaline urine.

(3) In addition to these certain forms of organized deposits are found. Spermatozoa, bacilli, bacteria, etc., may be detected by the microscope. Mucus may be found in fiber form mingled with cells of epithelium from the pelvis, bladder, ureter and kidneys.

Blood may be found in the urine and if it is found there is always present albumin. Various forms of casts may also be found in the urine containing blood corpuscles, oil globules epithelial cells, etc. The chief abnormal constituents of urine are (a) albumin giving origin to albuminuria and (b) sugar, producing diabetes. The different forms of albumin must be determined by precipitation. The two forms however in which they appear usually are

serum-albumin, and serum-globulin. The sugar found in diabetic urine is dextrose in form.

SECTION XIII.—Physiological Characteristics of the Urine and its Constituents.

A large quantity of water, salts and nitrogenous substances is separated by the kidneys. If an animal is fed upon a flesh diet the urine is clear and acid, very abundant in urea, phosphates and uric acid. If the diet is vegetable, as in the herbivora, the urine is not clear, it is alkaline in reaction, is very rich in carbonates and poor in phosphates, instead of uric acid being hyppuric acid. The nature of the diet very much alters the urine; hence, if the diet is rich in alkaline salts the blood is rich in these salts and this influences the urine. In the case of a mixed diet the urine is intermediate in character. Of the water excreted from the body in the human subject about 40 per cent is eliminated by the skin and lungs, and 60 per cent by the kidneys. If the diet is wholly or almost wholly animal flesh the amount of water excreted by the urinary system is increased to 70 per cent. If the quantity of urine is increased the amount of solid matter eliminated will also be increased, urea being generally increased from 3 to 4 per cent. If the supply of water is cut off from the bodily system the amount of urine is diminished normally about one fourth to one fifth. In the case of the use of drugs that are quickly dissolved, the substances in solution may be found very shortly after being taken, in the urine, for example, iodide of potassium.

(1) UREA. The chief organic constituent of urine is urea, $N_2 H_4 CO$ It is generally regarded as an amide of carbonic acid. The average amount of urea excreted in 24 hours is about 30 to 35 grams. It is the principal nitrogenous waste excreted from the body. It contains about 46 per cent of nitrogen and contains less carbon in proportion to nitrogen than any other organic substance, the result of proteid oxidation. If we know the amount of urea secreted in a given time, we can estimate the amount of proteid destroyed in the process. The quantity of urea excreted depends principally upon the food and its nature. When an animal is starved the amount excreted is lessened, gradually diminishing until a minimum is reached before death takes place. The formation of urea takes place in the liver and as the blood in the renal vein has less urea than the blood in the renal artery, it is said that no urea is formed in the kidneys. Even after the kidney is extirpated, urea is still found in large quantities in the blood. It is brought to the kidneys for excretion in the blood, the epithelial cells taking it out of the blood and passing it to the tubular lumen for elimination. Containing, as it does, N it must be derived from proteid substances, or rather from the albuminoid tissue elements or from nitrogenous proximate principles of the food. The quantity of urea excreted is not influenced by muscular activity but is distinctly increased when a diet rich in albuminous materials is taken.

Hence, it is concluded (a) that muscle when actively working does not produce nitrogenous waste and that, therefore, its contractile activity is not accompanied by oxidation of its own substance in the form of N, but rather by the burning of certain carbonaceous materials that are deposited in the muscle substances.

(b) A part of the proteid food material is in some way converted into urea. We have seen that the trypsin of the pancreatic juice converts some portions of the proteids in the food substance into leucin, tyrosin, etc. When leucin and tyrosin are introduced into the alimentary canal the amount of urea in the urine is increased, but no leucin appears in that fluid. There is, therefore, good ground for believing that the leucin formed by the paucreatic juice in the digestive process is at least one of the sources of the urea of the urine. If leucin is present in the alimentary canal it will doubtless be absorbed and carried to the liver in which the urea is found. This substance is not present in the muscular, nervous and glandular tissues of the body aside from the liver. This leads to the conclusion that one of the functions of the liver and also of the spleen is to transform leucin, tyrosin, etc., into urea. This conclusion is strengthened by the fact that in acute atrophy of the liver, a diseased condition, in which the activity of the hepatic cells is seriously interfered with, the urea of the urine is replaced by leucin and tyrosin. We said before that muscle does not by its contraction increase the excretion of nitrogenous waste but the corpuscles which compose muscles, as well as those fonnd in nervous glandular and their tissues are the centers of constant metabolic processes involving changes which imply the formation of certain waste products such as kreatinin, xanthin, etc., which are to be regarded as resulting from the chemical changes connected with the existence and development of the corpuscles. These substances are more or less readily diffusable and will be carried off from the tissues by the blood, ultimately reaching the kidneys, but the urine contains very little if any kreatinin. It was once held that the renal epithelium took up the kreatinin and converted it into urea, excreting it as such in the uriniferous tubules It is now known, however, that the extirpation of the kidney leads to the accumulation in the blood not of kreatinin but of urea. From this it is concluded that the formation of urea is not dependent upon or caused by the activity of the renal epithelium. As we have said, there are reasons for believing that the liver is actively engaged in the formation of the urea from leucin. It is conclnded from this by analogy that the liver also converts kreatinin into urea. If this is so, then the urea of the urine has a double source, being derived partly from kreatinin formed by the ordinary chemical changes taking place in connection with muscles and other tissues, and partly from the leucin resulting from tryptic digestion of the proteid food stuffs. Both the kreatinin and leucin according to this would be changed by the liver and possibly by the spleen into urea and the function of the renal epithelium would be confined to gathering up the urea so formed from the blood and to the excretion of it into the uriniferous tubules. If the urea and other forms of nitrogenous waste should fail to be separated from the blood as we find in certain renal diseases, their accumulation in the blood and in the body will lead to convulsions and other symptoms grouped under the term aræmia. Liebig defended the theory of the derivation of urea from the muscles. Muscular activity he believed to be carried on at the expense of nitrogenous substances either taken from the food or from the tissues. The food stuffs he regarded as either tissue forming or heat-producing, the former being albumin and the latter carbohydrates and fats. The albuminous matters he claimed was used in tissue upbuilding and in the production of muscular activity. The carbohydrates and fats by oxidation processes were converted into heat in connection with the formation of CO_2 and H_2O in the decomposition of nitrogenous matters urea and uric acid are formed while in the decomposition of non-nitrogenous matters CO_2 and H_2O are formed. If Liebig's theory is true muscular activity would increase the amount of urea and uric acid. Various experiments have been made to test this.

Fick and Wislicenus made an ascent of one of the Swiss Alps. For almost a day before ascending no nitrogenous food was taken, after which they spent 6 hours in ascending. They collected the urine (a.) prior to the ascent, (b.) during the ascent, (c.) 6 hours after the ascent, and (d.) after taking a meal of nitrogenous food, and (e.) during the following night. The work accomplished in ascending must have depended either upon nitrogenous food or albumin from the body. By estimating the work done and the energy produced by the albuminous materials it was found that less than 1-2 of the energy expended represented energy from the albumin. One gram of proteid is estimated to yield 1-3 gram of urea. Part of the proteid nitrogen assumes other forms as uric acid and kreatinin so that we cannot acurately determine the proportion. This indicates that the urea did not correspond in any sense with the wasts of the muscles. It was found that by the use of nonnitrogenous foods there was a diminution of N excreted both during the ascent and the period of rest and by the use of nitrogenous food the amount of nitrogen excreted increased. The amount of work done in the ascent was much in excess of the nitrogenous changes measured by the excretion of urea. These muscular changes depend, therefore, upon the metabolism of carbohydrates and fats and not upon the changes taking place in connection with nitrogenous food alone. This view has been confirmed by others who have shown that muscular exercise involves the increase of CO_2, a fact that depends upon the use of carbohydrates and fats in connection with muscular exercise. In addition it is found that there is found in connection with the muscles only very small traces of urea. This amount not being increased by muscular effort or exercise and no increase taking place in the amount of urea circulating through the muscle. These points seem to negative the theory of Liebig as to the muscle formation of urea leaving the liver as the chief if not the only source of urea.

Cyon made several experiments in transfusing blood through fresh liver at the temperature of the body finding an increase in the amount of urea after transfusion, some urea may have been washed out which already existed in the liver but even in this case some must have been formed as there was an increase from .08 to .176 grams of urea.

Shroeder experimented upon the liver of a dog when fasting and during digestion. He found that in the former condition by the transfusion of blood no urea increase was found, while in the latter condition there was an increase amouuting to nearly 30 per cent. In addition to this it has been found that when the liver becomes atrophied urea disappears altogether from the urine. Liebig concluded that in the dissociation of albumin in connection with the tissues urea was formed. Experiments by various physiologists have negatived this theory, the amount of urea found in muscles being very small and muscular activity not tending to increase the amount of urea. The amount of carbonic acid is increased by muscular activity, the muscular energy being derived from the nonnitrogenous food elements more largely, than that derived from nitrogenous food elements.

How is the urea formed? It is closely connected with the ammonia group and by the process of hydration, is easily changed to ammonia carbonate. It arises from the proteids by hydrolysis and oxidation, in which ammonia compounds are formed, being carried to the liver and changed to urea.

Drechsel found that cobamic acid was found in the urine of dogs and that ammonium carbonate could be converted into urea by deprivation of a molecule of water. According to him there are three processes. (a) Oxidation resulting in the loss of H. (b) Reduction in the loss of O and (c) dehydration resulting in the loss of water, the result being the production of urea. As the ammonium carbonate exists in the body, he claims that in this way urea is produced. It has been shown that by removing the liver of dogs the urea is decreased and the amount of carbonate is increased. It has been found recently that the amount of ammonia in the blood of the portal vein is three or four times that in the arterial blood, normally. It is claimed that these ammonia compounds are converted into urea in the liver so as to protect the arterial circulation. If the liver becomes deranged a large amount of ammonia is found in the blood and produces fatal results. This amount of amonia seems to arise from the decomposition of proteids in the stomach glands and pancreas during the act of secretion. The ammonia carbonate arises originally from the proteids and albuminoid foods, Drechsel thinks these are subjected to hydrolysis forming leucin, tyrosin, etc. These substances are then oxidized in the tissues forming CO_2, H_2O, and NH_3, the CO_2 and NH_3 uniting to form ammonium carbonate which passes to the liver and forms urea. This forms the basis of the carbonate theory of Drechsel in regard to the formation of urea. Urea is found even after the liver is removed. Some of the ammonia compounds found in other body tissues may be changed to urea in other parts of the body, Drechsel has produced urea external to the body by boiling the proteid with an acid. He used hydrochloric acid. In order to maintain the hydrogen evolution and keep out O from the air he mixed it with metalic zinc. In this decomposition he found lysatinin which when isolated in connection with barytan water produced urea. According to this, urea was obtained by decomposition and as the lysatinin is found in the body it is possible that the same process goes on in the body in the formation of urea. In addition to what we have said as to the formation of urea in the liver, it is found that in the case of phosphorous poisoning the amount of urea is greatly decreased and that by destroying the blood corpuscles and freeing hæmoglobin in the blood the amount of urea is largely increased.

Noel-Paton has shown that the bile secretion and the urea formation are directly related to each other. Therefore, he concludes that the chief source of urea formation is the destruction of the red blood corpuscles in the liver and in the spleen.

(2.) URIC ACID. It is found constantly in the urine but in smaller quantities than the urea. It is closely allied to urea and is a result of the same metabolic changes. It is a more complex substance than the urea, one of the uric acid molecules dividing into two molecules of urea and oxalic acid. Next to urea the most important element in the urine is the uric acid, about .5 to 1 gram per day normally, chiefly in combination with kreatinin and xanthin are excreted. In birds and reptiles it is the chief nitrogenous element taking the place of urea as the chief product of proteid metabolism. It is probably produced in the same way as urea as it is increased by a diet rich in albuminous materials. It occurs in such small quantities in the human subject that it has not been investigated as yet. It is sometimes regarded as an intermediate stage in the metabolic changes in the proteids which immediately preceeds urea. It has been suggested that on account of the close relation of uric acid, to xanthine and hypoxanthine the uric acid is produced from these by oxidation.

Harbacewaky has shown this in the lymphoid tissue including the spleen, there is a substance from which uric acid is formed. He thinks that uric acid represents a product of metabolism in connection with white blood corpuscles, as urea does in the case of red blood corpuscles. The close affinity of uric acid and urea is brought out by the fact that uric acid takes the place of urea in birds and reptiles and is produced in the liver. If the kidneys are removed in the case of birds, uric acid accumulates in the blood indicating that the kidneys do not produce the uric acid. The removal of the liver, however, leads to the diminution of uric acid, ammonium salts taking its place. From this it is concluded that the proteid metabolism produces ammonium salts which are

carried by the liver and therefore transformed into uric acid. Uric acid can be produced from urea and glycocol. In the human subject ammonium salts are found in the urine in cases of liver atrophy and phosphorous poisoning.

In certain physiological conditions such as fevers and leucocythemia there is an increase of uric acid. This last confirming the view of the formation of uric acid in connection with the white blood corpuscles. In human urine it exists not as a free acid but as an acid salt in combination with potassium and sodium, ammonium and calcium. These salts are soluble in urine but when the urine cools they deposit as urates, later forming the uric crystals. Closely connected with uric acid we find several nitrogenous substances with the xanthine family which are found in the urine in very small quantities. They representing a certain amount of proteid metabolism, but what amount or what kind of metabolism they represent is not yet known. If uric acid accumulates in the system it may give rise to gout or when excessively found in the urine may form renal or vesical calculi.

In connection with the waste of nervous and muscular tissue kreatin is formed. Closely related to it is kreatinin which is formed in the kidneys being always present in the urine. Kreatinin is not formed in the blood so that the change from kreatin to kreatinin does not take place in the blood so that it is probably transformed in the kidneys or at least in the urine as it is collected in the kidneys Kreatinin occurs in urine in the human subject to the extent of about one gram daily. It is closely connected with kreatin, being kreatin in hydrated form which is a constant element in muscle, being separated from muscle food and eliminated as kreatinin. It is partly derived from muscle food and partly from metabolism in the body tissues. Urea is not found in connection with the muscles, while kreatin occurs in large quantities, this large quantity being transformed according to some into urea and also into kreatinin. Hyppuric acid is found in place of uric acid in the urine of herbivora. Hyppuric acid is a benzoil amido acetic acid. It is always found in very small quantities in human urine to the extent of .5 grams daily. If a vegetable diet is used this amount is increased. If benzoic acid is fed to animals hyppuric acid is found in the urine, the benzoic acid uniting with glyceral in the kidneys. The vegetables yield benzoic acid, and hence the increase of hippuric acid in the urine. The small quantity, however, found in the urine normally, must arise from the proteid metabolism probably as a product of proteid decomposition, especially in the proteid putrefaction in the large intestine In addition to these, sulphur is excreted in the urine in the form of ethereal salts with compound aromatics. Phenol, indol, skatol and cresol are formed in the large intestine in connection with the decomposition process, part of these being eliminated in the fæces and part in the blood absorption being carried through the liver where they are united with sulphuric acid forming sulphates which are excreted in the urine. Tyrosin is also occasionally present in the urine. (3) The aromatic substances of urine are absorbed from the small intestine and excreted through the kidneys. These arise from the decomposition taking place in albuminous materials in connection with the pancreatic juice. In constipated conditions they are found in the urine on account of the large increase in the system. Urobilin found in the urine is derived from biliruben which results from the hæmoglobin decomposition in the liver. Indican is probably derived from indol which arises from the putrefaction taking place in the large intestine under the influence of a micro-organic ferment. The saline matters depend upon the salts in the food. The chloride of sodium is the necessary element in the urine excretion. If it is withdrawn from the food supply the amount excreted is diminished and a minimun quantity continues to be excreted till death results. Phosphates are derived from the food elements and from the tissue metabolism. Sulphates arise from the albuminous decomposition.

Various physiological phenomena have a bearing upon the urine. In the case of a child, the amount of urine is much larger in relative proportion to size, also a larger proportion of urea and salts. In old people, the amount of urine is decreased and the solid substances are also diminished. The male excretes more urine than the female and the male urine is more fully supplied with solids. During sleep the urine accumulates, being more solid and having more of the pigments and acids. The excretion in connection with the skin uses up more of the water so that the solid matters are increased. The phosphates being increased and the other solid substances decreased. During pregnant conditions the urine becomes deeply colored and manifests a greater density due to the presence of triple phosphate crystals, particles of fat and fungus organisms.

SECTION XIV.—Mechanism of the Excretion of Urine.

The kidney is a compound tubular gland the ultimate terminations of the tubules; the glomeruli being lined by a layer of single squamous epithelium while the other parts of the glandular tract, for example, the convoluted tubes have an epithelium which is much more distinctly of a glandular character and which, from the shape and appearance of its cells we should expect to be engaged in the separation of materials from the blood. The blood reaches the kidneys through the renal artery immediately upon the arterial system, the branches of which pass into the substances of the kidney and by dividing ultimately form the afferent vessels to the glomerulio. In each glomerulus, the afferent vessel breaks up into capillary loops which being reuniting from the efferent vessel. This being of smaller calibre the afferent; hence, the blood in the glomerulus is at a considerable pressure and the rate of the flow is slow. Under the influence of this pressure water containing highly soluble and diffusible salts in solution filters through the walls of the capillary loops of the glomerulus and the epithelium covering the glomerulus into the Bowman's capsule. From thence it passes into the uriniferous tubules. The efferent vessel after leaving the glomerulus breaks up into capillaries which are distributed over the surface of the convoluted tubules and it is believed that the large epithelial cells in these tubules extract from the blood in the capillaries, certain substances, the nitrogenous matters and perhaps also pigments and excrete them into the uriniferous tubules. As the blood passes through the organs certain matters are lost which constitue the urine which after secretion in the kidneys is transferred by the ureters to the bladder. This waste may take place by a transudation from the blood by the active secretion of the epithelial cells or by both of these processes. The process of secretion is dependent upon blood pressure. Increase in blood pressure producing an increased secretion. If the renal circulation becomes too slow indicating a great fall in blood pressure the secretion is arrested. Severe loss of blood decreases the secretion, the increase of aortic pressure causing an increase and the decrease of aortic pressure, a decrease of the secretion. Hence, that process by which the urine is separated from the blood by the kidneys may be said to consist of two parts. (1) A filtration process in Bowman's capsule by which a large quantity of water with certain solid salts in solution is rapidly removed from the blood. (2) A true excretory process. The epithelium of the convoluted tubules by its vital activity separates nitrogenous and other matters with some water from

the blood. The process of filtration must necessarily be dependent upon and must largely be influenced by the blood pressure in the smaller arteries, in the kidneys for the flow of urine ceases when the pressure in the uriniferous tubules is greater than the pressure in the blood vessels, for example, when the ureter is ligatured. If the pressure in the renal artery is decreased the urine secretion is diminished. The rate of secretion depends upon the difference in pressure between the renal arteries and the urinary tubules. The secretion is dependent upon the difference in pressure between the vessels of the kidneys and the ureter. By the increase of pressure in the kidney the urine secretion is increased. The filtration process is not to be regarded as identical with ordinary filtration through dead materials, for the cells of the capillary walls and those of the epithelium covering the glomeruli undoubtedly exercise some influence in determining what substances shall pass through them. On the other hand, the secretory process is only influenced in a secondary degree by the blood pressure, being dependent on the activity of the cells lining the convoluted tubules and these cells are, as far as known, stimulated to their activity by various substances contained in the blood. The condition of the blood influences the secretion. The Malpighain bodies are so arranged structurally that the pressure in the glomeruli is great and the blood flow is slow. Thus, the water, salts and albumin will be separated from the blood by filtration and collected in Bowman's capsule. An increase in the amount of water used for example, by profuse drinking, increases the excretion of water by increasing the blood pressure. The pressure theory of itself is insufficient to account for the secretion. While the blood is alkaline, the urine in the human subject is acid. There is also a larger proportion of urea and salts in the urine than in the blood. Certain of the substances found in the urine are not found in the blood for example kreatinin, as the urine differs in its character from the blood, it cannot be simply a transudation from the blood. If the renal vein is compressed or ligatured, the pressure in the glomeruli will be increased but the amount of urine will be lessened. According to Ludwig the blood pressure causes the transudation of the blood plasma through the capillary walls of the glomeruli. After this the fluid is brought into contact with the epithelial lining of the tubules and into connection with the lymph around the tubules, the water is then reabsorbed by the lymph and also into the blood capillaries.

If we take account of the glandular character of the epithelium of the tubules and assume that the cells are active then we can account for the difference between the urine and the blood as to the matters found in the two fluids especially the fact that certain substances are found in the urine that are not found in the blood. Certain substances are found in the cells indicating the cell activity, for example the crystals of uric acid. It seems to be not so much, a question of blood pressure as of the velocity of the blood flow together with the existence of certain substances such as O, urea, and the salts, which assists the secretory process by acting within the cells. The rapid rate of the flow assists in the secretion of the urine by bringing these substances into close contact with the cells and inducing activity upon the part of the cells. The secretory process, therefore, takes place in connection with the cells, urea, uric acid, and salts, being first secreted in these cells, these being washed out by the water which is filtered in connection with the glomeruli. The cell activity, however, in reference to these substances depends upon the rapidity of the blood flow and upon the amount of water found in the blood. An increase, therefore, of the water or of the velocity of the blood flow will increase the urine secretion. The blood pressure in the small vessels of the kidney will be increased (1) by the general increase of blood pressure due to the increased force or frequency of the cardiac contractions or to the contractions of the smaller arteries all over the body. (2) By the contraction of the small arteries in reigons outside of the kidneys, for example, the skin, the intestines, etc. (3) By the relaxation of the renal artery or its main branches. The opposite conditions will of course, diminish the blood pressure in the smaller renal vessels.

SECTION XV. Innervation of the Kidneys.

The actions and influences of the central nervous system upon urine secretion and excretion is not well known, as very little investigation has been made in connection with the minute nerve connections of the kidneys. The exact nervous tracts along which particular impressions travel to the vessels of the kidney are not definitely known. The nerves to the kidney come from the renal plexuses and the smaller splanchnics. Some fibers have been followed into the papillæ. The section of the spinal cord below the medulla lessens or causes to cease altogether the flow of urine. This is probably due to the great fall of blood pressure produced in the vesseis of the kidneys in connection with vaso-motor paralysis. If the lower end of the cord after division is stimulated the blood pressure rises in the vessel of the kidney as well as the body generally, and the urine secretion is increased. The higher centers have an influence upon the urine secretion and excretion. Emotional conditions increase both the secretion and the excretion. The central source of the renal nerve is found in the floor of the 4th ventricle close to the vagi roots. If the medulla is punctured in this region the amount of urine is increased and it is found to contain albumin and blood-serum. The section of the renal nerves leads to polyuria and the specific gravity of the urine becomes lessened. The same result to a less degree follows the section of the splanchnic nerves, a fact to be explained in connection with the dilatation of the renal artery. The splanchnic contains the fibers of the vaso-motor nerves from the 1st dorsal. The renal vessels and those in the intestines become paralyzed. On the other hand, stimulation of the distal portion of the divded splanchnic nerve causes contraction of the renal artery and a diminution or complete arrest of the flow of urine.

The kidney, like the spleen, is subject to rythmic variations. The kidney diminished in size when the renal arteries contract increasing when the vessel calibre increases. The tracings that mark the increase in the renal volume indicate that the changes follow the respiratory and cardiac pulsations. Vaso-motor action influences the change in the size of the kidney, for example, an excessive supply of blood to the vaso-motor center area produces vaso-motor stimulation, causing diminution in the volume. There are no vaso-dilator fibers to the kidneys as the stimulation of the splanchnic branches of the sympathetic causes diminution in the renal volume. There is an intra-renal nervous arrangement, although it is not as yet completely understood. If water and urea are injected into the blood there is a contraction of the kidneys followed by dilitation. The same results follow when all nervous connection is cut off from the central nervous system.

Mosso in his experiments introduced the actheter into the bladder and connecting it with a recording instrument to discover the volume of the bladder. He found that the bladder could be entirely emptied without the use of the abdominal muscles. He claims that the feeling of fullnes and the desire to urinate, results from the stimulation produced by the presence and pressure

of the urine. The bladder is very sensitive, constant changes taking place under reflex stimulation, the pressure of the bladder depending on reflex stimulation as much as on the amount of urine present. It is this that causes the desire to urinate under psychic influences. This may pass away by the action of the sphincter urethrae until some new reflex stimulation produces this desire to urinate again. The longitudinal and the circular coatings of the bladder have distinct nervous connection. If stimulation is applied to the sacral nerve branches it produces strong vesical contractions of the longitudinal coating in the case of the dog. If the sacral nerves are stimulated on the one side there is a contractions of the bladder only upon one side. This has led to the conclusion that the longitudinal coating of the bladder is regulated by the sacral nerves. If the hypogastric nerves which have fibers from the dorsal and upper lumbar region of the cord, are stimulated, it produces vesical contractions chiefly in connection with circular fibers at the neck of the bladder. Thus, it is concluded that the hypogastric nerves regulate the circular fibers in contracting to evacuate the bladder. Micturition when viewed in general seems to be purely voluntary. By voluntary action the bladder muscle fibers become contracted, relaxing the sphincter exterus by the inhibitoin of the spinal center, contracting the abdominal muscles and the ejaculator urinæ muscles, resulting in the distruction of urethral resistance and the flow of urine. This, however, does not explain certain facts in connection with micturition. (1) In the case of the dog when the lumbar region of the spinal cord has been entirely severed from the dorsal region, micturition is not destroyed. There is no voluntary effort in this case. All the micturition process therefore, must take place reflexly. When the bladder is filled stimulation applied mechanically to the abdominal walls or to the anus will completely empty the bladder. The ejaculatory muscles contracting, producing rythmical increase in the flow of urine. This has led to the conclusion that there is a center of micturition in the lumbar reigon of the spinal cord subject to stimulation. This center in the human subject is found also in the cord above the center that regulates the genitals. That this center is one of reflex action has been proved in connection with the bladder. The bladder pressure is subject to great changes. Not only do we find changes in pressure accompanying the respiratory action but we also find active variations produced reflexly causing sufficient stimulation to evacuate the bladder. (2) When the urethra is obstructed so that the full bladder does not produce sufficient stimulation to empty it, there are found numerous and powerful contractions of the vesical walls which are purely involuntary. These, while insufficient to empty the bladder, produces great pain sometimes. As the tension increases the fibers become more actively contracted. In this way the simple distention of the bladder aside from any involuntary effort may give rise to strong contractions sufficient usually to empty the bladder, but in cases of obstruction, insufficient to empty the bladder but producing rythmical contractions. From this it is concluded that micturition is not purely voluntary. In confirmation of this it is found that micturition is involuntary in certain abnormal conditions where the spinal cord is paralyzed or injured in some way. The same is true of micturition resulting reflexly from sensory stimulation. The afferent impulses in this case pass to the center in the spinal cord. The same thing is true in the case of emotions productting micturition. In both cases the impulses pass from the brain, along spinal nerves to the spinal centers, producing micturition reflexly through the micturition center. Thus, the action is not direct upon the bladder walls but reflex through the micturition center. This idea is not disproved by the fact that when the bladder is paralyzed this is taken as the symtom of cerebral or spinal diseased conditions. The real reason is the effect produced upon the micturition center, either destroying its action or weakening its force. In cases in which we find an irregularity in micturition particularly in children, the cause is to be sought in the excitement on the reflex center in the spinal cord, under slight stimulation, where incontinence arises in connection with spinal or cerebral diseased conditions, it depends upon the weakening of the activity of the spinal centers, so that instead of a complete emptying of the bladder there is a constant dripping of the urine. The spinal nerve center or centers that regulate the innervation of the bladder are situated in the lumbar region of the spinal cord.

According to Goltz between the 2d and 5th lumbar nerves, the sensory fibers from the bladder and urethra pass into the cord through the posterior roots of the 1st, 2d, 3d, 4th, and 5th chiefly, the 2d and 3d, spinal nerves in sacral region. If these fibers are stimulated they excite reflexly the motor fibers to the bladder in the anterior roots of the 3d and 3d, spinal nerves.

The motor nerves regulating the muscles of the urethra and the Sphincter urethræ leave the cord through the anterior roots of the 2d, and 4th spinal nerves in the sacral region. The bladder gets motor fibers, according to Langly from the fibers of the 2d, 3d, 4th, and 5th lumbar nerves, passing to the bladder through the sympathetics, hypogastrics and inferior mensenteric ganglia and also from the 2d and 3d spinal nerves in the sacral region. The stimulation of the former produces a weak and of the latter a strong contraction of the bladder. This center in the lumbar region of the cord is connected with the cerebrum by fibers which are inhibitory. It is said, also by some that nerve fibers pass immediately from the brain through the cord to the sphincter urethræ, bringing it under the control of the will. Some sensory fibers reach the bladder through the hypogastric nerves. the stimulation of these resulting in the reflex stimulation of the motor fibers in the other, hypogastric, resulting in the contraction of the bladder the reflex taking place through the inferior mesenteric ganglion. Here we have a peripheral ganglion acting as a reflex center. When the urine is voluntarily voided this higher center sends down impressions to the voluntary muscles which control the sphincter. Others say that impulses from the higher centers must pass through the spinal center. There are also vaso-constrictor fibers but their course and action are unknown. It the spinal cord is injured procucing irritation higher than the lumbar centers the distension of the bladder takes place, the urine being retained, sometimes passing from the urethra by drops. When micturition is voluntary a a little urine passes into the urethra arousing sensory stimulation which excites the spinal centers. This spinal center is constantly active normally securing the firm closure of the neck of the bladder and preventing the escape of the urine. When the sensory impulses reach the center it is inhibited and as a result the neck of the bladder yields the impulses from the center being conveyed to the bladder and the abdominal muscles resulting in micturition. Similarly, certain psychic influences from the brain affect micturition under the control of the will, although it is objected to this psychic influences that it seems to overbear the normal tonic condition of the spinal center. It is in this way explain influences coming to the spinal center from any part of the body affecting micturition, and producing micturition involuntary ejection of the urine.

SECTION XVI. Micturition.

The excretory organs consist of the ureters, the bladder and the urethra. The urine is being continuously separated from the blood, being secreted continuously. There may be variations in the flow in normal conditions but it never ceases as the suspension of renal activity results in the urine suppression and produces death quickly. Small currents pass along the tubules that collect the urine, these currents passing from the orifices of the excretory tubules into the calices and are collected in the renal pelvis. It is then carried along the ureters partly by pressure, partly by the force of gravity and partly by peristaltic contractions of the muscular walls of the ureter and is then discharged into the bladder. It is then ejected from the bladder through the urethra. When collected in the bladder its regurgitation into the ureter is prevented by the oblique manner in which these tubules perforate the walls of the bladder and by the small valves formed by the vesicle mucous membrane at the orifice of each ureter.

If one of the ureters in the living animal is laid open and subjected to stimulation at a point along its path peristaltic waves may be seen originating at the point of stimulation and passing to the kidney and the bladder. Even when there is no stimulation applied artificially there are waves peristaltis sometimes regularly and sometimes irregularly, these peristaltic contractions all moving in one direction from the kidney towards the bladder the force and frequency of these contractions depending upon the urine excretion and secretion. That these contractions do not depend upon the presence, or action of urine, however, may be shown by the fact that these contractions occur when the kidney and ureter have been taken out of the body. These contractions seem to be of a muscular character and also rythmic originating in the muscular coating of the ureter just as we found the muscular cantractions of the heart. These do not depend upon nervous connections as when a portion of the ureter is entirely isolated at the center of the ureter in which no nerve connection exists, these contractions are found to take place. While these contractions are not caused by the urine secretion, they occur with greater frequency when the urine secretion is active, indicating that the degree of peristalsis of the renal pelvis and the ureter depends upon the secretion of the urine.

There are three layers in the walls of the ureter, the intimia consisting of a mucous coating inside of which is a muscular coating and outside a fibrous coating; connective tissue fibers constitute the tunica propria of the mucous membrane in the midst of which are found cellular elements, the tunica propria passing into a submucous coat. The tunica propria is covered with stratified tesselated epithelium In the pelvic portion of the kidney there are racemose glands and also in the upper portion of the ureter. The muscular layer consists of two fiber coatings, the external being circular and the internal longitudinal. In the lower portion of the ureter there is a third layer outside of the other two, consisting of longitudinal fibers. The same layers are found in the bladder. Small racemose glands are found in the tunica propria of the fundus. The muscular coating consists of an internal and external layer of longitudinal fibers with a middle layer of circular fibers between them.

Nerve fibers pass to the muscular fibers of the pelvis and ureter and in the bladder there are also groups of ganglia. In the female uretha we find a mucous membrane whose tunica propria consists of delicate connective tissue with numerous capillae chiefly at the external orifice. It is very vascular and contains a number of racemose glands. In the male urethra there are some differences. The epithelium of the prostatic portion is like the epithelium of the bladder, while in the membraneous portion it becomes stratified cylindrical epithelium and in the cavernous portion the simple cylindrical epithelium. The flat stratified epithelium exist in the fossa navicularis. Probably the urine is driven through the ureter by peristaltic contractions of the walls. It rapidly flows from the pelvic portion of the kidney into the bladder and the bladder is slowly filled as the external orifice is closed. The muscular fibers of the walls of the bladder are kept in a constant state of tonic contraction, the degree of contraction varying at different times. When the bladder becomes emptied contractions of the bladder take place and it becomes folded. As it gradually fills again it is distended, and the fluid that is being collected being held in the bladder by the resistance that arises in connection with the elastic fibers in the urethra walls closing the urethra. If the spinal cord is intact even a pressure of twenty inches of water will be sustained, whereas, if the lumbar region of the cord is destroyed the pressure that can be sustained is very much lessened. This points to the fact that urine is prevented from passing out of the bladder by the muscular tonicity which is preserved by the nervous connectiou with the lumbar region of the spinal cord. This nervous action bears upon the circular fibers chiefly forming the sphincter vesicae. These fibers are continuous with the circular fibers of the bladder and probably they contract after the other circular fibers of the bladder, completing the emptying of the bladder. Hence the resistence to the outflow of urine depends upon the tonicity of the muscular fibers round about the prostatic portion of the urethra, forming the external sphincter vesicae of Henle. When in consequence of the accumulation of urine a certain amount of tension is caused upon the bladder wall the amount of urine necessary to do this being in inverse proportion to the degree of tonic contraction of the muscular fibers. Contraction of the muscular fibers is set up probably by a reflex action and this assisted by the contraction of the abdominal muscles, drives the urine with force into the urethra the sphincter vessicae relaxing or contractions, being overcome. The urine cannot be driven up the ureters by bladder force. The ureter orifices being slanting, strong pressure tending to close and keep them closed. After the bladder has reached a certain limit of tension the nerves in the bladder walls are stimulated. If the distension increases the muscle fibers of the Sphincter become contracted by reflex action, the expulsion of the urine being closely associated with the escape of a few drops of urine into prossattic portion of the urethra. When the bladder is full there arises a desire to urinate, this desire being produced, as some say, by the passage of a few drops from the bladder into the urethra. This sensation becomes conscious and rerults in an effort during which the bladder is contracted by peristaltic action, the urethral resistance being overcome and the urine flowing freely through the relaxed sphincter vesicae. When we speak of the bladder as full we do not mean necessarily filled with urine, as the desire to urinate may exist where only a small quantity of urine is in the bladder. There is a continuous tonicity in the bladder, although this tonicity varies considerably. If the tonicity is great the increased contraction may produce the desire to urinate with only a small quantity of urine and if the tonicity is small a large quantity of urine may be necessary, hence the desire to micturate depends upon (1) the condition of tonicity in the bladder and (2) on the amount of urine found on the bladder, the tonicity depending upon nervous regulation. It is certain that a free flow of urine follows this occurrence as it passes along the urethra, the last portions of the urine are thrown out of the urethra in drops. This being caused by the irregular muscular contractions of the bulbo-cavernous portion of the urethra, the contractions pressing upon the urethra.

Englemann has carefully studied the ureter movements. The contractions of the muscular coating consisting of an internal longitudinal and an external circular layer takes place spontaneously at varying intervals of 10 to

20 seconds, in the case of the rabbit commencing at the kidney and moving towards the bladder along the ureters as a peristaltic wave. By this peristaltis the urine is driven into the bladder intermittently. Observations have been made in the human subject which confirm the view in cases where there was found a misplacement of the bladder. Englemann found that by artificially stimulating the ureter at a particular point, peristalsis was produced in both directions. In the absence of ganglia he concluded that the peristalsis originated in the muscular coating. The wave passing along the muscle just as in the transmission of contraction along the muscle fiber. The originating cause of the stimulation of the ureter is found in the accumulation of urine in the upper part of the ureter next to the kidney, stimulating the muscle to contraction. Difference of opinion exist as to whether the contractions take place spontaneously, or requires stimulation of the urine. Englemann found that by dividing the ureter near to the kidney, the contractions in the part attached to the kidney continued. This seemed to indicate that the contractions result spontaneously from the muscular tissue. When thus originated there is a definite knowledge of the contractions and of its action in forcing the urine through the ureter.

In the bladder we find a muscular coating of two layers, one internal circular and the other external longitudinal. There is also a longitudinal layer in the interior of the circular coat. There is not the same distinction between the layers that is found in the intestines forming a single continuous layer. The circular layer is stronger at the cervical end forming a sphincter in connection with the urethral opening, called the internal sphincter vesicæ. Outside the bladder there is a muscular coating forming the sphincter urethræ. When the urine reaches the bladder it is kept inside by the elastic action of the portion at the urethral opening and the tonicity of the sphincter vesicæ. As the urine accumulated the sphincter urethræ comes into action. The sphincter uethræ is under the control of the will, although normally it is subject to reflex action. Regurgitation of the urine is prevented by the curved course of the ureters through the bladder walls, the pressure of the urine closing the ureters. When the bladder is filled there is excited sensation corresponding with the filling of the bladder and the desire to urinate followed by micturition. Micturition consists of the bladder centraction accompanied by the relaxation of the sphincter urethræ resulting in the forcing of the urine out into the urethræ. This contraction is very strong and it is assisted by the contraction of the abdominal walls, producing an increased abdominal and pelvic contractions assisting in emptying the bladder. Much difference of opinion exists as to the cause of these contractions of the bladder and the abdomen. When the bladder is filled, sensory fibers in the bladder are stimulated reflexly by contracting the muscular coating in the bladder and driving out some urine into the urethræ. By the passage of these drops of urine into the urethræ another stimulation is aroused producing the desire to urinate. Thus, the will adds its force to the musculature of the bladder. The bladder may be prevented from being emptied by the voluntary contraction of the sphincter urethræ, if the bladder is not overfilled. If it is, then the voluntary control is limited to the abdominal muscles and sphincter urethræ, the normal bladder contractions being involuntary and reflex througe the center of micturition in the lumbar region of the cord. Some have claimed that the bladder contraction is also voluntary.

INDEX.