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THE PRINCIPLES OF PHYSIOLOGY

BY

JOHN GRAY McKENDRICK

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BY

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PREFACE

This is in no sense a Text Book. It is rather an attempt to state the leading principles and facts of physiology, and more especially of human physiology, in such a way as will be understood by an intelligent reader who has had no special scientific training. If the perusal of this little book leads the reader to wish to know more of this fascinating science, which, in a sense, is the meeting-point of many sciences, he is referred to the Bibliography, and the aim of the writer will be accomplished.

J. G. M.

Maxieburn,
Stonehaven,
January, 1912.

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THE PRINCIPLES OF PHYSIOLOGY

CHAPTER I

ITS SCOPE, AIMS AND RELATIONS

1. PHYSIOLOGY is the science which describes and endeavours to explain the phenomena manifested by living beings. It may also be said to treat of the changes that occur in living matter. It deals with that special mode of activity we call *Life*.

2. Living beings are divided into plants and animals. There are many forms difficult to classify; these seem to belong to either the plant or the animal world, according to the point of view from which we regard them. All living things, however, show certain general characters, by which we know they are alive. They are developed from a parent or parents, they require food and oxygen,

they pass through a number of stages in their existence, they reproduce their kind, and they die. It may not always be easy to observe some of these phenomena in the lower forms, but we find that their bodies are composed of matter that possesses certain properties, and we characterize such matter as being alive.

3. One of the lessons of scientific investigation is that in the study of phenomena we find *transition*—a series of changes, and the gradual passage of one state into another—while a superficial examination may appear to establish clear lines of division between different departments of knowledge. Thus we distinguish between that which we say is dead matter, and that which we consider to be alive. More careful examination, however, shows that certain properties may be the same, or similar, in both dead and living matter. Thus a crystal, which we regard as dead, grows and increases in size in accordance with physical laws. Living matter also grows and increases in size, but by a different process from that of a crystal. So that mere increase in size, in certain conditions, may characterize

both that which is dead and that which is alive. Changes even in the minute structure of both dead and living matter may occur. For example, it is known that slow changes may happen in the structure of even hard metals. Particles of gold may penetrate into a mass of solid lead, and solid bodies may even, by slow movements, sink into an apparently brittle mass of cobblers' wax. Slow changes probably occur in all kinds of matter, even the most dense and durable. Thus molecular changes, or, in other words, movements, may occur in matter which we call dead. Molecular movements also occur in living matter, so that such minute movements do not enable us to distinguish between what is dead and what is alive. Both dead and living matter, again, are subject to the laws of gravitation, and many electrical and optical phenomena are manifested in a similar way by so-called dead and by so-called living matter.

4. There is no difficulty, however, in recognizing many of the phenomena of life in one of the higher forms, whether it be a plant

or an animal. Thus one of the higher plants is rooted to the soil, from which it mainly derives nourishment; it spreads its branches and leaves and flowers to the air, and it breathes. An animal of the higher orders shows active movements such as running or leaping, it breathes, it requires food, and it can produce heat. We find accordingly that there are phenomena to be observed and explained in both the plant and the animal. It is the province of the physiologist to study those phenomena and to offer explanations. The field of work, however, is so immense that the science naturally subdivides into *plant* and *animal physiology*. The first is a division of the science of *Botany*, while that of the latter falls into the domain of the *Zoologist*. Thus, in a sense, all the phenomena of living things fall into those two sciences, but, by common consent, the task of describing and explaining the phenomena on which life depends, is relegated to physiology, and this again may be subdivided into the physiologies of the various animals. We discuss the phenomena occurring in the body of man as *Human Physiology*, but we might equally well discuss the physiology of the domestic animals, such as that of the horse or ox, or the physiology of birds, or, indeed, of any group of animals. It is found that no sufficient explanation of many vital phenomena can be given by the study of one animal, or group of animals, and accordingly knowledge may be brought to a focus in the department of science called *Comparative Physiology*.

At one time the word physiology expressed all that we now term physics (*phusis*, nature, *logos*, a description), a description of natural phenomena in general. For many years, however, its meaning has been limited to the discussion of phenomena as these occur in living beings.

5. But all science is in a sense one, and accordingly we find that the compartments of knowledge we call the sciences are related to each other. Physiology is closely related to, and largely depends on, three sciences: *Anatomy*, *Physics* and *Chemistry*. A general acquaintance with these sciences is of paramount importance to any one about to enter

on the study of physiology. One should know something of the plan of structure met with in the great subdivisions of the animal kingdom. The student of human physiology, for example, should be acquainted with the general anatomy of the human body, and of its various organs, although much may be learned from the dissection of one of the lower mammals, such as the rabbit. Not only is it necessary to study the forms and relations to other parts of the various organs, as seen by the naked eye, but also the minute structure of the organs and tissues as revealed by the microscope, and by modern technical methods of preparing these for examination. This is the department known as *Histology*, a department of science that in recent years has made enormous progress. The demands of one science stimulate another, and we find an example in the development of the modern microscope, which, both in its mechanical and optical arrangements, may be regarded as a nearly perfect scientific instrument. The methods of hardening, cutting into thin sections, and staining by various colouring matters are now highly skilful and accurate. Histology has both a morphological side, in as far as it deals with form, and a physiological when it treats of the functions performed by these tissues. Further, much information is furnished to the physiologist by the examination of the body at various stages of growth, and more especially in the earlier stages. Thus the study of the formation and early development of the embryo, and tracing the origin of the tissues, and the gradual building up of the more complicated organs, have thrown light on vital phenomena. This line of research is known as *Embryology*.

The body is also the theatre of many phenomena of a *chemical character*; indeed it may be said that the phenomena of life depend essentially on chemical changes. As we shall see, food and oxygen are introduced into the body, and, by chemical changes, often of a complicated kind, many chemical substances are formed, some of which are built into the tissues, while others are thrown out as effete. Many of the operations in the digestion of food and in the formation of substances in the blood are purely chemical. *Physiological Chemistry* has as its field a description of the physical and chemical character of the substances forming the tissues and existing in the fluids of the body. It also gives an explanation of the chemical processes occurring in the body. This department of science has also made great progress in recent years. At one time it was thought that certain substances formed in the body could be formed only in living matter. The synthesis of urea by Wöhler in 1828 upset this notion. This experiment laid the foundations of organic chemistry. Since then hundreds of chemical substances found in plant or animal tissues have been formed synthetically by the chemist by the operation of chemical methods. It is remarkable, however, that in living matter such substances are formed by molecular action and by hidden processes, while the chemist can only form them by the agency of high temperatures, and the action of powerful substances such as acids or oxydising or reducing substances. It is possible that the processes of nature and of the chemist may in essence be identical, or at all events similar, but this is doubtful.

6. The laws of *physics* are applied by the physiologist to the investigation of the motions of the solids and fluids in the animal organism. Thus the movements of the limbs in locomotion are mechanical, the movements of the blood in the circulation are subject to the physical laws of hydrodynamics, the interchanges of gases between the air and the blood in respiration are to be explained as special cases of the transfusion of gases through thin membranes, while the actions of the eye and ear can only be understood by the study of optics and acoustics and their application to these highly specialized mechanisms. The absorption into the blood of nutrient matters, after their preparation by digestion, and the elimination of waste matters from the blood by various organs, are so far to be explained by the laws regulating the passage of fluids through thin membranes, and which are studied by the physicist. It may indeed be said that physical processes are more or less involved in all the phenomena

of living matter. It would also seem that electricity plays an important part in vital activities, or, at all events, it is intimately related to the intricate and hidden molecular phenomena on which life depends. Finally, the phenomena of the living being can only be accounted for by their consideration in the light of the modern doctrine of the *conservation of energy*, a doctrine which may be said to have originated in the study of these phenomena. The history of this great idea shows that the endeavour to account for animal heat and the relation of food and oxygen to the production of heat and of animal movements, was one of the first steps towards the building up this doctrine, which lies at the foundation of all physical, chemical and biological science.

7. Thus, physiology rests on a tripod of three sciences—Anatomy, Chemistry, and Physics. It brings to bear on its problems all the information that can be gathered from those sciences, considered in their broadest relations, and while physiology has its own methods, it may be said to be the mechanical

and chemical interpretation of phenomena happening in living matter. We shall see, however, that in the present state of the science there are not a few phenomena which cannot be so explained. Such phenomena are provisionally termed *vital*. Meantime we may note that as physiological science advances, vital phenomena are more and more regarded as special examples of the operation of chemical and physical laws. Still there are at present, and it is not going too far to assert that there must always be, some phenomena that cannot be so explained. Thus it would appear to be impossible ever to account for feeling, willing, thinking, and other mental (*psychical*) states or processes by any purely physical or chemical operations.

CHAPTER II

THE CHARACTERISTICS OF LIVING ORGANISMS

Certain of these have already been referred to. We may now consider some of the characteristics of living beings more fully.

8. *Physical structure.* No living matter ever assumes a crystalline form, but crystals may be imbedded in it. Living matter is always soft, jelly-like, diffluent, readily permeated by water, oxygen, and the crystalloids. It is matter in a colloidal state, which, as it permits of the free play of molecular interchanges, has been termed a *dynamical state of matter*. The colloidal shape is not, however, peculiar to living matter, as it is shown by certain conditions of silicic acid, peroxide of iron, etc. The firmer portions of living matter are always soft; they readily absorb water by imbibition. It has been supposed that living matter consists of still more minute

particles, possibly of irregular form, and that water fills up the spaces between such particles. Such molecules are assumed to be in a state of incessant movement, and these movements are associated with the absorption and liberation of water. A watery consistence is essential to the phenomena of life. Movements of minute particles of matter in a fluid are well illustrated by the Brownian movements seen under the microscope, magnifying say 250 diameters, if we squeeze and examine a little bit of fresh vegetable tissue. The minute particles are seen to be in a state of incessant vibration.

9. *Chemical composition.* Of the seventy elements known to chemists only from eighteen to twenty have been found in living matter, and of these the chief are oxygen, hydrogen, nitrogen and carbon. With these are associated, of the non-metals, sulphur, phosphorus, and chlorine; of the alkalies, sodium and potassium; of the alkaline earths, calcium and magnesium; and of the metals only one, iron. Minute quantities of other substances have been found, such as argon, silicon,

fluorine, iodine, bromine, manganese, and copper, but the presence of some of these substances may be accidental. It should be noted that carbon and nitrogen, along with hydrogen and oxygen, are essential to life. Oxygen and hydrogen are often in the proportions that form water—2 of hydrogen to 1 of oxygen. From these elements complex chemical substances are built up. Thus the living matter in the cells of a plant, mainly under the stimulus of light, so combines carbon, hydrogen and oxygen as to form starches, sugars, and fats; and it may also form still more complex chemical substances, known as proteins, which contain carbon, hydrogen, and oxygen, and the all important element nitrogen. Such bodies, often termed *proximate principles,* thus formed in a plant, may become the food of an animal and be built into its tissues, or be directly used up in various transformations connected with vital activity. The term proximate principle was given by the earlier physiological chemists, because they thought that certain substances, such as the proteins (albumen, etc.) existed in the tissues or fluids as they were known to the chemist. We now know that this is an assumption. These so-called principles probably only arise from the decomposition of matter that was once alive. One of the characteristics of these complex organic substances, whether as found in the bodies of plants or animals, is their *instability*. They are liable to split up into simpler bodies, and this splitting up is always associated with the liberation of energy, chiefly as heat or movement. Thus, in living matter two apparently opposite chemical processes are continually at work; there is either the building up of simpler substances into more complex ones, such as the formation of starch from the elements carbon, hydrogen, and oxygen, or the pulling down of complex substances into simpler ones, as the resolution of starch into carbonic acid and water. In the upbuilding process, often termed *anabolic*, energy is locked up, or becomes latent, while in the pulling down process, termed *katabolic*, energy is liberated and becomes kinetic. Thus starch (or oil), when burnt, that is oxidised, yields carbonic acid and water, and energy is liberated as heat, which may be transformed into the motion of a steam engine and caused to do work. Living matter is thus continually undergoing a series of chemical changes of composition and decomposition, as a result of which there is an incessant renovation of its particles. It would appear that chemical changes are a necessary condition of the action of living matter; part of the living matter dies, is decomposed, or rather, its decomposition is coincident with its death, and the dead matter is thrown out of the body. New matter is then added from the outer world. There is thus a perpetual exchange between the dead and the living worlds, which may be termed a *circulation of matter between the dead and the living*. Portions of the earth's surface now dead were once part of the bodies of living beings, and may again enter into the living state.

10. *Form and Mode of Growth.* As already pointed out, living matter is jelly-like in its consistence. It often changes its form, as may be seen in an amoeba or in the colourless cells in the blood. At the beginning of

existence, the typical form is nearly spherical, as seen in the ovum, and also in many of the minute cells of which the body is composed. Living matter never assumes crystalline forms; it does not grow like a crystal, by the deposition of new matter on its surfaces, but by absorbing matter into its substance and usually transforming this into matter like itself. A crystal does not transform, and it grows by the deposition of new layers on its surface; living matter can transform, or *assimilate*, and it can grow by the transformed matter becoming part of its substance. It is remarkable, however, that dead matter may assume forms very similar to the forms of living matter. In certain media crystallisable substances may take on organic shapes, and various mixtures of soaps, gums, etc., may form a froth which, under the microscope, may show forms very similar to that seen in living stuff. In some circumstances even the movements of living matter may be imitated. Thus, a highly complex substance called protagon can be extracted from yolk of egg by hot alcohol. If a minute portion be placed under the microscope and a drop of water be allowed to impinge on the edge of the morsel, curious twisted or spiral structures may be seen shooting out. These *myelin* forms, as they are called, are instructive, as showing lifelike movements in dead matter—depending on changes in surface tension. Some have even asserted that living matter is essentially a kind of froth, and that the structural forms are similar to those seen when one blows a mass of soap bubbles Walls and partitions may then appear, and even one part may seem to be within another, not unlike certain structures seen in a thin section of living matter. *Such imitation-forms, however, do not imply life.*

11. *Evolutional History.* A living being, during the course of its existence, passes through phases that follow each other in a certain order. It originates in a germ which is developed in a parent, that is, in a previously existing being that has essentially the same structure and properties. This germ, which is known as the spore, seed, or egg of plants and animals, is a cell, a comparatively simple

structure. After its separation from the parent body, it is capable of independent existence, and, under favourable circumstances, of developing into a new individual, in most respects similar to that from which it derived its origin Living beings form a continuous series, from the first appearance of life on the earth until now. The offspring have usually characters which they have inherited from their parents, but they may develop new characters which may arise from new circumstances affecting them during their own lives. If these characters, either inherited or acquired, are transmitted to descendants, the phenomenon is known as *heredity*. Each living being shows a period during which there is a *maximum vital activity*, when the liberation of energy is greatest. During life it passes by stages up to this period; then, after a stage of maximum activity, the powers of the organism slowly decline. During its life an organism undergoes change of form, there is increase of mass, and it shows increasing complexity of structure. These changes, however, do not go on indefinitely.

A condition of fully developed organization is reached, for each kind of living thing, reproductive processes occur, the processes of life go on more slowly and less completely, and finally some part of the machinery of life breaks down, and *death* occurs. This is the last stage in the evolution of that particular organism. After death of the tissues of the body, it is submitted to the action of external agencies, both physical, chemical, and vital (the vital being due to the activities of micro-organisms of an inferior order), and these ultimately reduce it to the simple elements of which the body was at first composed.

12. A living being is affected during every moment of its life by the medium in which it lives. The medium furnishes the material necessary for its existence. Dead matter is supplied to take the place of the living matter that has died after having done its work. External modes of energy, such as heat, light, and electricity, act upon it, and energy is supplied also by the chemical changes brought about ultimately, but by many subsidiary

processes, by the interaction of the elements of food and of the oxygen of the air. There is thus action and reaction between the living being and the conditions in which it lives. These conditions are termed the *environment.* The living being has, within limits, the faculty of suiting itself to the surrounding conditions. Such a power, which is a necessary condition of the existence of every living being, is known as its *variability. It is the power of adaptation to external conditions.*

CHAPTER III

THE ACTIVITIES OF LIVING BEINGS

13. LIFE is a condition of activity. In the body of one of the higher animals we see activities manifested in various forms. Some of these have already been referred to, but we must now give a statement of those which it is the special province of the physiologist to explain.

(1) *Animal Heat.* The body of an animal (we may leave plants out of this discussion, although much that will here be indicated also applies to them) has a certain mean temperature. In so called warm-blooded animals, such as the birds and mammals, the temperature of the body varies only through a few degrees, even although there may be very considerable variations in the temperature of the surrounding medium. Thus the temperature of the body of a man,

taken by a suitable thermometer placed for a few minutes in the arm-pit, varies in a state of health only within a few fractions of a degree above or below 98° Fahr. whether the temperature be taken within the Arctic circle or at the Equator. On the other hand, the temperature of the body of a frog or of a fish varies as the surrounding temperature rises and falls. Such an animal is said to be cold-blooded. The terms cold-blooded and warm-blooded are not scientifically appropriate. A warm-blooded animal, such as a man or a dog, has a temperature that is fairly constant, whereas a so-called cold-blooded animal, like a frog or a fish, has a temperature that varies considerably with the temperature of the medium in which it lives. But if the temperature of the air surrounding a man's body is lower than 98.4° F., then the body must be constantly losing heat by radiation and conduction. The questions at once arise: What is the origin of this heat? By what channels is it lost from the body? By what arrangement is the temperature kept so uniform? Are there heat regulating mechanisms? These questions will be afterwards discussed. *It is to be noted that living matter can only perform its functions within a narrow range of temperature.*

(2) *Motion.* Animals move and parts of their body move. They leap, run, or walk, the chest moves in respiration, and the heart beats. These movements are accomplished by the *muscular tissues*, which are the seat of intense activities. Energy is here liberated as *motion.* The physiologist has to study the structure, nutrition, and the contractile functions of muscular tissue. He finds that every contraction of muscular tissue is associated with active chemical changes occurring in the tissue, by which there is a breaking down of muscle substance, and the formation of chemical substances of a simpler nature. These chemical changes are intimately connected with the breathing of the living muscle substance, that is to say, they depend on chemical phenomena in the muscle substance which require the presence of oxygen and lead to the elimination of carbonic acid and of other

waste matters. The muscle substance must be repaired. This is done by nutritional changes in the muscle. Materials are supplied in food, which, after many chemical and physical changes, are rebuilt into the muscle substance, thus renewing both the matter and the energy that have been expended in the muscle during its contractile activity. The muscle liberates energy as heat, motion, and, to a small extent, under the form of electrical change.

(3) *Secretion.* This is a peculiar form of vital activity occurring in glands, of which there are many forms. The product of this activity is termed a *secretion.* The essential structures in a gland are a thin membrane on one side of which we find living cells, and on the other, and in intimate relation to these cells, a network of minute blood vessels, termed capillaries. From the capillaries a fluid exudes from the blood, and this fluid supplies nutrient material to the living cells. These cells take such material into their substance and complex chemical processes then go on. Each cell is a minute laboratory in

which special substances are formed. The cell gradually is filled with these substances and then it bursts, liberating its contents, or in some cases there seems to be a gradual removal from the cell of the products of its secretion. The matters thus collected from innumerable cells become the secretion of the gland. We may take as an example the secretion of saliva. The cells of the salivary gland elaborate the materials that form the secretion. In particular, they form a peculiar body, known as *ptyalin*, belonging to the class of ferments. There is no ptyalin in the blood. It is formed in the cells of the gland. Nor is it at once formed from materials supplied by the blood. There is at least one antecedent substance, probably more than one, marking stages in the gradual formation of ptyalin. In like manner, the cells of the mammary gland elaborate the complex fluid, milk, and those of the pancreatic gland the remarkable bodies found in the secretion of that gland, all of which are ferments. *Secretion, however, is essentially a form of growth depending on the activities of the secreting cell.*

(4) *Nervous activities.* All the various vital activities are more or less controlled and regulated by the nervous system, which may be regarded as the *master system* of the body. This consists of the brain, spinal cord, ganglia, and nerves, but it may be more shortly described as formed of nerve centres and nerves. The nerves pass to and from the centres, connecting up all parts of the body with those centres. Nervous energy may originate in the centres,—brain, or cord, or ganglia,—and it may stream out along the fibres in the nerves to various organs, such as muscles, glands, blood vessels, and, in some animals (such as the electric fishes), electric organs. This energy, as to the nature of which we know little, awakens the activities of those organs. Under its influence, muscular fibres will contract, the cells of a gland will secrete, the walls of small vessels will alter their calibre, and an electric organ will be the seat of electrical changes. The centres, in their turn, receive from the periphery of the body, from the sense organs, and from all other organs, nervous impulses that awaken activi-

ties in the centres. These activities may cause other impulses to stream outwards to the various organs and thus stimulate them, or they may, as in the higher brain centres, be associated with various states of consciousness, such as sensations, emotions or intellectual and volitional processes. *Thus the whole body is bound together, and controlled and regulated, by the nervous system.*

CHAPTER IV

ORIGIN AND DEVELOPMENT OF THE INDIVIDUAL

14. AFTER a general survey of some of the fundamental characteristics of living beings, we now turn our attention more especially to the physiology of man, and the first question that naturally presents itself is—How does he, as an individual, originate? At once the answer will be given that he springs from parents, a mother and a father. This easy answer, however, gives no information, and one may be rather startled by the statement that he springs from structures of microscopical dimensions, that he owes his origin to the combination of an egg or ovum with a body called a spermatozoon. In this he resembles the great majority of living things. To appreciate, however, the wonderful story of how this comes about, it is neces-

sary to fix our attention on what is known as a *cell*, the first and smallest unit of structure from which the tissues of the body are formed. If we examine the body, say of a rabbit, we find it is built up of various tissues. Thus we find the flesh, consisting chiefly of muscular tissue, the cartilages or gristles, the bones, the brain and structures related to it (constituting the nervous system), and the various glands and internal organs, such as lungs, stomach and liver. But if, by appropriate methods, such as are used in the examination of tissues and organs by the microscope, we pursue the analysis farther, and more especially if we study the tissues at various periods in their development, we find that they all originate from cells. A cell is a small bag or vesicle, varying in size from the 1/6000 of an inch to bodies just visible to the naked eye. Antecedent even to cells, there is a still more primitive substance known as *protoplasm*. It is a jelly-like, colourless, or faintly yellow substance, having often embedded in it minute granules. It may either form large masses, as in certain fungus-like forms, or it may be in small portions, like the well-known amoeba found in stagnant pools. One of its most remarkable characteristics is that of free movement, by which it may change its shape from time to time. It has the power also of absorbing organic matter from the medium in which it lives, and of converting this into protoplasm. It breathes: using up oxygen and producing carbonic acid.

Protoplasm is always a constituent of living cells. A cell may consist simply of a bit of protoplasm, or it may consist of protoplasm having embedded in it a minute more or less globular body known as a *nucleus*, or it may have a thin envelope surrounding it called the *cell wall*. A typical cell, therefore, consists of a cell-wall, the protoplasmic contents of the cell, and a nucleus. It can be shown that the cell substance (or *cytoplasm*), and also the nucleus, often show a network of very fine fibres or a coiled fibre, and that the contents are not structureless, as was at one time supposed. The minute fibres, or portions of fibres, found in the nucleus have a special significance. These take up certain stains readily, and the material forming them is termed *chromatin* or colourable stuff. Further, the minute bodies thus stainable are termed *chromosomes*, and it is remarkable that the number of chromosomes is almost invariably the same for the cells of each species of animal. The cell also contains matter that is not stainable, or *achromatin*, as well as matters formed from the substance of the cells, such as droplets of fat, granules of a starchy substance called glycogen, and other bodies, as in secreting cells already mentioned. There is usually a layer of absolutely structureless matter next the cell wall termed *hyaloplasm;* and it can be shown that certain matters may pass through this layer while others cannot do so. This is of importance in connection with absorption of matters by the cell and the elimination of matters from it. It is important to note that the cell is the theatre of activities, of a physical, chemical, and vital nature, and that probably all the phenomena of life may be manifested by a cell. It often shows irritability, or the power of responding to a stimulus, a property which may be the beginning of psychical states. These activities are all more or less controlled and regulated by the nucleus. If a cell be divided artificially so that one portion of the protoplasm contains the nucleus, while the other has no nucleus, the latter portion soon dies, but the other portion remains alive, and may grow and perform its functions as before. Cells apparently secrete certain matters which collect outside the cells, forming intercellular matter, so as to form a tissue, such as cartilage or gristle; in other cases, this intercellular matter may form a fibrous structure impregnated with earthy matter, as in bone; or the cells themselves may be modified so as to form more complicated tissues, such as muscle; or the cells may cover such surfaces as the skin, or, as secreting cells, line the pouches of glands. *All tissues are primarily formed of cells, and the activities of these tissues are the sum of the activities of the cells.* All cells arise from cells. *Omnis cellula e cellula.*

15. The formation of the body is the result of the union of two primitive cells, an ovum,

or egg, derived from a female, and a spermatozoon, derived from a male parent. The ovum is a small spherical vesicle about 1/100 of an inch in diameter. Imbedded in its protoplasm there is a large spherical nucleus, termed the *germinal vesicle*, and, in the nucleus, there is a still smaller body, the *germinal spot*. Both the cell protoplasm and the nucleus show a network of fine fibres, and in the nucleus of the human ovum there are chromosomes. The ovum is formed in a special organ, the *ovary*, and at certain periods the ovum is extruded into the Fallopian Tube, a duct which leads to the uterine cavity.

The male element, the *spermatozoon*, is a minute body consisting of a head and a long vibratile tail. The total length is about 1/500 of an inch, while the head, which is the important part, is about 1/10 of the length. The head represents the nucleus of a cell in which the spermatozoon has been developed, and it contains the all-important chromatin. The spermatozoa are formed in enormous numbers in the cells of a special organ, the *testis*.

16. It is remarkable that both the ova and the spermatozoa appear in the same part of the early embryo, a layer of germinal matter, which is cut off, at an early period, from the matter that is to form the body of the individual, whether male or female. The exact origin of the reproductive elements has not been clearly established. It is suggestive that immature ova are found in the ovary of a female long before birth. There they lie dormant, or undergo very slow changes till puberty. The early origin of spermatozoa has not been clearly established; the cells that produce them are not active till the beginning of adolescence. In the female the extrusion of ova continues until perhaps fifty years of age, but the production of spermatozoa by the male may last through a long life. Many intricate arrangements for the nutrition and support of both are found in the ovary and testis. Of themselves, at all events in the higher animals, neither male nor female element alone can originate a new individual. The two must unite and blend together This is *fecundation.* Antecedent

to this event, however, both the spermatozoid and the ovum undergo remarkable changes, which have been studied in certain of the simpler forms of animals, but while for obvious reasons these phenomena cannot be followed in a human being, there is every reason to suppose they are of the same nature. These phenomena consists essentially of various forms of cell division, by which, in the case of the spermatozoa, these bodies are increased four-fold, while in that of the ovum, by a process of splitting and separating of the chromosomes in the nucleus or germinal vesicle, half of the chromosomes are extruded and are practically lost. Thus, suppose the number of chromosomes before these changes to be twenty, ten are thrown out and ten are retained. Fecundation then occurs by the blending of the head of the spermatozoid (containing chromosomes from the male parent) with the germinal vesicle of the ovum (containing chromosomes from the female). It would appear that the number of chromosomes in the fecundated ovum is now doubled, that is to say, in the case we have supposed, the number is again twenty, but half are now maternal and half are paternal. *This is believed to be the physical basis of heredity, as it is assumed that hereditary characteristics are conveyed by the chromosomes.* This statement implies that hereditary matter has been transmitted not from parents only but from grandparents and possibly from individuals of many previous generations.

17. The fecundated ovum then divides into two, each of the two into four, and so on until a large number of cells are formed—and by a remarkable series of processes, known as *Karyokinesis*, each cell, when it divides, transmits to its two descendants exactly the same number of chromosomes, one half representing the male while the other half represents the female side. *Thus, according to modern theory, every cell in the body may possess hereditary characteristics.*

18. The early cells form certain layers from which all the organs and tissues of the body are developed.

The early embryonic tissue in which the future being is formed is composed of two portions. One part is called the *trophoblast.* It has to do with the formation of structures for connecting the ovum with the mucous layer of the uterus in which the embryo is to spend the first part of its existence. The other is the *blastoderm,* in which the future being is to be developed. The blastoderm divides into three germinal layers, an inner called the *endoderm,* an outer named the *ectoderm,* and between the two a third, the *mesoderm.* The embryo at first consists of only two layers, the endo- and ecto-derm, but at a very early period the mesoderm makes its appearance and is probably formed by the other two. In turn, the mesoderm splits into two layers, one of which becomes closely adapted to the ectoderm, to form a thick layer, the *somatopleure,* while the other clings to the endoderm and becomes the *splanchnopleure* The somatopleure becomes the wall of the body, and the splanchnopleure forms the outer wall of the alimentary canal. Between the two there is a space, the body cavity, which, in full development, constitutes the pleural and peritoneal cavities, in which lie the viscera of the body. Several layers may combine in the formation of the various organs and tissues. A transverse muscular partition, the *diaphragm*, divides the body cavity into two, the *thorax* and the *abdomen*.

19. From the *ectoderm* are derived the epidermic covering, the skin, and structures such as nails and hair; the epithelium of the glands of the skin, of the mammary gland, of the anterior part of the mouth, of part of the alimentary canal at the anus, of the anterior part of the nasal openings, of a portion of the pituitary body, the enamel of the teeth; the whole of the nervous system; the epithelium of the sense organs, and a portion of the suprarenal bodies. *It is important to observe that the nervous system and the sensory layers of the organs of special sense are formed from the outer layer of the embryo.*

20. Passing to the inner layer, the *endoderm*, we find it develops into the epithelium of the alimentary canal and the glands communicating with it; the epithelium of the two Eustachian tubes passing from the throat to the

tympanum, or middle ear; the lining of the tympanum itself; the epithelium of the respiratory passages, larynx, trachea, bronchi, and pulmonary air cells; the epithelium of the thymus and thyroid bodies; and the epithelium of the urinary bladder and of a portion of the urethra.

21. From the epithelial portion of the *mesoderm*, that is the somatopleure portion of the mesoderm, are developed all the voluntary muscles, the epithelium of the Wolffian and Müllerian ducts (primitive excretory organs); the epithelium of the excretory tubules of the kidneys and Wolffian bodies; the epithelium of the lining of the body cavity, sometimes called endothelium, the cortex of the suprarenal body, and some of the cells of the ovary and testis. *Possibly the germ cells are formed in this layer, but their place of origin has not been conclusively established.* Lastly, from the *mesenchyme*, that is the splanchnopleure layer of the mesoderm that has become associated with the endoderm, we find developed the connective tissues, involuntary muscles, the spleen, the lymphatic

glands, lymphoid or adenoid tissue in various organs, the lining epithelium of the heart and blood and lymph vessels (endothelium) the red corpuscles of the blood, and probably, but not certainly, the white corpuscles of the blood.

22. As already pointed out, the portion of the ectoderm that takes no part in the formation of the embryo is known as the trophoblast. This structure by and by comes into relation with the maternal tissues in the uterus and an important organ is formed, the *placenta*. By means of this organ the blood of the mother is brought into close relation with the blood of the offspring. A thin membrane and layers of cells intervene, and both respiratory and nutritional changes are carried on. The foetus breathes by the placenta, receiving oxygen from the mother's blood and giving up to it carbonic acid. The placenta also supplies materials for the nourishment of the foetus, and no doubt proteins, carbo-hydrates, fats, saline matters, and water are thus supplied, for the growth of the foetal tissues. At this period the tissues of the foetus are so nourished

as to ensure constant growth, while its sluggish life implies the production of a minimum of waste products. Thus growth goes on steadily and with astonishing rapidity. Tissue after tissue and organ after organ are formed, not in a definite order as regards time but contemporaneously, as if some kind of directive agency were at work. There are even examples of something like foreknowledge in the building up of the fœtus. Stores of glycogen are supplied for the nutrition of embryonic tissues. Iron is collected in the body of the foetus, from the mother's blood, so that an abundance of this metal, all important for the development of red blood corpuscles, is found in the newly-born when in the new condition of existence it is nourished by milk, which contains only a small supply of iron. Iron is needed, but as the milk does not contain enough of iron for the wants of the organism during lactation, the child utilizes the iron that has been already stored. In development, too, one of the most remarkable phenomena is the formation of organs in most of which tissues take part that are supplied by different layers of the embryo.

Thus, as an example, the framework of the liver is formed by connective tissue from the mesoderm, while the hepatic cells are derived from the cells of the endoderm and have the same origin as the cells lining the alimentary canal. To bring those two structures together to form a liver implies growth from different points and at the proper time.

23. Each tissue and organ has its hereditary peculiarities. These are often obvious in the features, the colour of the eyes and hair, and the stature; they are seen also in many of those mental peculiarities that contribute to the making of character and individuality; but they are not so evident in the arrangements of individual organs. There can be little doubt, however, that hereditary characters may affect all the tissues and organs of the body. *They are not merely superficial.* All of these remarkable phenomena that lie at the beginning of life are physiological processes; but science has not yet been able to trace them from the physiological standpoint. Interest in them, at present, is mainly morphological, that is as regards the laws that

regulate form in living mechanisms, but physiological considerations cannot be excluded. How are we to explain the forces in operation in producing the cleavages and movements that are apparent? How can we account for the nutrition of the chromatin, said to be the fundamental basis of heredity, by which it multiplies itself? Is there, as some suppose, an inner world of molecular movement in the chromatin, by which, influenced by nutrition and by a kind of struggle for existence and survival of the fittest, new combinations of chromatin-particles are effected so as ultimately to produce individuals different in some ways from their parents, or are the phenomena only under the laws of chance like the results of the rattle of the dice box? These are all profound questions lying at the very basis of physiology.

24. Not many years ago it was not uncommon for physiologists to think of the reproductive elements, ova and spermatozoa, as practically structureless, and to regard them as being composed simply of granular, jelly-like matter. Since then, owing to the improve-

ments in microscopes and in the methods of microscopy, structure has been rendered apparent where it was not supposed to exist. Physicists had endeavoured to fix physiologists on the horns of a dilemma. Either an ovum must have structure, which physiologists at one time doubted, otherwise complicated structures must have been evolved out of what was structureless (which is inconceivable) or, if the physiologists admit the existence of structure, then the minute cubical capacity of the fecundated ovum could not contain all the organic molecules necessary to account for the transmission of hereditary characteristics. Since this criticism was made, in the first place, structure in a fecundated ovum has been admitted, and, in the second, we now have more accurate estimates of the size of atoms and molecules than was then available, with the result that, even in the minute cubical mass of a fecundated ovum, there is room enough for all the molecules necessary to transmit, by their combinations, all that is required to account for even minute characteristics in offspring. Further, the new physica conception of an atom or molecule as matter in which there is incessant movement, to and fro and rotatory, makes it still less difficult to conceive of a physical basis for heredity.

CHAPTER V

DEVELOPMENT OF TISSUES AND ORGANS

25. We have seen that the first organized matter that forms the physical basis of life is protoplasm. Then appears the more specialized form, the cell, and from the primitive cells the layers of the embryo are developed. From these layers the various organs and tissues of the future being are produced. All embryonic tissues are very similar to each other, consisting of protoplasm, in which appear nuclei and cells in a more or less rapid state of transition. From these the various tissues are formed. The cells covering surfaces, either external, or those lining the alimentary canal and the ducts and pouches of the various glands, form a layer termed *epithelium.* Such epithelial cells may be close together to form a single layer, or the layer may consist of cells three or four deep,

in different degrees of development, those on the surface being fully formed. It is to be noted that all free surfaces are covered by such cells, and it follows that *matter can neither enter the tissues of the body, nor issue from them into the external world, without passing through an epithelial layer* Such matters do not, however, pass through epithelium as a fluid passes through a filter, but the matter is modified chemically and physically by the epithelial cells.

26. Other cells become differentiated into tissues that form, as it were, the framework of the body, moulding the shape of organs, and supporting their constituent structures. These are called the *connective* tissues. This variety of tissue is so abundant as to exist in every organ, while it forms a framework for every other tissue. Sometimes it is soft and consists of delicate fibres forming networks or membranes or cords (as in sinews), but it may be infiltrated with earthy matter, and form a hard structure of bone, and again it may be hard, without earthy matter, in cartilage or gristle. Lying in it, we always find cells in a

condition of vital activity, and these cells produce the intervening substance, such as the fibres of ordinary connective tissue, the solid basis of gristle or the hard substance of bone. All such cells are engaged in forming a framework to support other structures, and they can also repair any injury to an organ, such as may be caused by a cutting instrument. Thus, a wound of the skin is healed and filled up by connective tissues, as seen in a cicatrix or scar. So abundant is connective tissue that if we can imagine the body to be immersed in a fluid which dissolved all the tissues except connective tissues, we should still have a cast of the body, spongy-like in structure, formed of this tissue. It is richly supplied with blood by fine capillaries and by numerous lymphatic spaces and channels for drainage of lymph. No doubt it is the scene of active physiological changes.

27. The next tissue of importance is *muscular* or *contractile tissue*, of which there are several varieties. The masses of flesh we find on the trunk and limbs are composed of a variety of this tissue called *striated muscle*,

on account of its striped appearance when examined microscopically. It consists of a mass of elongated nucleated cells, each an inch or two in length, having pointed ends, and its minute structure is so complicated that it is still one of the puzzles of histologists. The cell substance has become highly differentiated into disk-like structures, which give the tissue an appearance of striation, that is of bands passing transversely across the fibre. There is also a differentiation into longitudinal structures called sarcostyles or fibrils, each of which shows striation, due to the existence of sarcous elements, or sarcomeres. When a fibre contracts the sarcous elements contract and a fluid substance, the sarcoplasm, is pressed out in both directions till it is arrested by a thin membrane, the membrane of Krause. This membrane passes transversely across a fibre and separates bundles of sarcostyles. The sarcous elements are doubly refractive, while the other parts between are singly refractive. There appears also to be a very fine reticulum, with longitudinal meshes, in the fibre. Another variety, called *non-*

striated muscle, consists of elongated cells, with no striation. It is found chiefly in the wall of the stomach and bowel, in the ducts of glands, in the walls of blood vessels, and in the skin.

Finally, we find the power of movement, or contractility, manifested by many cells, usually isolated in a fluid, or embedded in a tissue. Thus the white blood corpuscles (leucocytes of several varieties), cartilage cells, the cells in bone, connective tissue cells, the cilia (hair-like structures) found on some epithelial cells, are all contractile and are capable of changing their shape. All forms of contractile tissues are for purposes of movement. Thus the movements of the limbs in locomotion, and the movements of the chest wall in respiration, are effected by means of striated muscles. Again, the slow contractions by which, during digestion and absorption, the food stuffs are propelled along the alimentary canal, are effected by non-striated muscle. The heart beats, the changes in the calibre of the smaller arteries by which the quantity of blood going to a part is regulated, movements in certain ducts, as in the ureter (the duct passing from the kidney to the bladder), the contractions of the skin, are all effected by non-striated muscle. The contractions of cilia create a current in one direction, as in those in the respiratory passages causing a movement of air and mucus towards the opening of the respiratory passage. The leucocytes, by their contractions, can pass out of the vessels into surrounding tissues, and there they may seize hold of, kill, and digest foreign organisms, such as many bacteria and bacilli that cause disease. Probably, also, by this power of ingesting foreign bodies, they take part in processes of nutrition. All contractile tissues, except the isolated cells, are related to the central nervous system by nerves that pass to and from these centres to the contractile tissues. They are also very richly supplied with blood vessels, and they are nourished by the fluid that passes out of the vessels, and bathes every fibre. This fluid, called *lymph*, carries away all excess of fluid, and also many substances in solution that are formed by the destruction of muscle substance, or of chemical matters in it, during contractile activity. Contractile tissue constantly requires oxygen, and it constantly produces carbonic acid; this is so, even during the resting of muscle, but, when it contracts, much more oxygen is used and much more carbonic acid is produced. So complicated are the chemical processes in contractile tissue that there is still uncertainty regarding them.

28. The controlling and regulating tissue is *nervous tissue.* It is found in the brain, spinal marrow, ganglia, parts of the organs of sense, and in nerves, and it consists of nerve fibres and nerve cells. These will be more fully considered when we treat of nervous actions. Suffice it to say here that nerve fibres generate and conduct what we term a *nervous impulse*, a change, the true nature of which we do not know. Such an impulse, issuing from a nerve centre, such as a portion of the spinal cord, may travel to a muscle and cause the striated tissue to shorten, when there may

be movement of a limb; or it may, when it reaches the non-striated muscle in the bowel, cause slow ring-like movements of the tube (peristaltic); or it may affect the number and strength of the heart beats, or it may cause the walls of small arteries to contract and thus regulate the amount of blood flowing through them; or it may stimulate the activity of a secretion, as seen, for example, in the increased flow of saliva when a sapid substance is in the mouth, or even when the sight or thought of delicious food has the same effect. The electric discharge of an electric fish is also under the control of the nervous system, which also appears to affect the light of the firefly, glowworm, and even the light of the luminous organs found in some fishes that live in the profound darkness of the depths of the ocean. Finally, in the nerve cells that form the main part of the nerve centres, such as the brain and spinal cord, there are molecular changes of which we know next to nothing, and yet on these all nervous activities depend, even those associated with mental processes.

29. It would seem that during countless ages evolution has slowly built up a great variety of animals. This evolutionary process has also affected more or less every tissue. We may detect primitive types of tissue, such as we find in the embryo, in the tissue of the placenta and umbilical cord, in the cells between the bodies of the vertebrae, in the vitreous humour of the eye, in the so-called lymphoid tissue found in various organs, and in connective tissues generally. Cartilage or gristle has preceded bone. Non-striated may be regarded as more primitive than striated muscle. Even some striated muscles seem to be more primitive than others. These muscles are usually pale, but certain muscles, such as the semi-membranous muscle in a rabbit's leg, are red. Red muscles contract more slowly than pale muscles, and their structure seems to be of a lower type. Nervous tissues have passed through many forms, until we reach the highly complicated cells of the nerve centres. The nervous elements of the sense organs also show differentiation as we pass from lower to higher forms. Thus the

retinal elements of the eye of a codfish are very different from those in the human retina. Little attention has yet been paid to the evolution of tissues, and the question of whether it has been brought about by the agency of external circumstances on a particular tissue, or by the influence of one tissue on another, cannot yet be answered. *It is striking, however, to observe that evolution, which depends on physiological processes, affects not merely the outward form but even the tissues that build up the body of an animal.*

CHAPTER VI

MATTER AND ENERGY IN THE LIVING BODY

30. *Matter* and *chemical processes.* As has already been pointed out, the phenomena of life depend on chemical changes occurring in the body. These changes are largely oxidations, that is the union of oxygen with certain constituents of the body, and decompositions, that is the splitting up of more complex chemical substances into simpler ones. There are also, to some extent, reductions, that is, the taking of oxygen from chemical constituents; and there are syntheses, the reverse of decompositions, or the building up of complex substances from simpler ones.

31. We are still ignorant of the exact nature of many of the chemical processes occurring in living tissue, but they may be shortly noticed.

(1) *Oxidation* is the most common chemical reaction By continuous processes of oxidation complex bodies are split up into simpler ones. Thus by oxidation, protein, such as exists in white of egg, may be split up into leucin, tyrosin, glycine, and the fatty acids; uric acid into urea, allantoin, oxalic acid and carbonic acid. Oxidation has been carried out by the chemist, with the production of chemical substances the same as those found in the fluids and tissues; and the inference is that in the living body they are also produced by oxidation. But in living matter the processes are obscure, and there are probably intermediate steps still unknown. There can be little doubt that oxidations occur almost wholly in the tissues; but we must avoid taking too mechanical a view of the nature of oxidation in living matter. There is no such phenomenon as the direct union of oxygen with carbon, or with hydrogen, as in burning a candle. The combustion of a candle will always yield, for a given weight, the same amount of carbonic acid and of water, and the same amount of

oxygen will be used up. But there is no parallelism in the so-called oxidation in living stuff Oxygen may disappear in the process, and the amount of combustion products cannot always be accounted for by the amount of oxygen used. Oxidation in living matter is a complicated process.

(2) *Reduction* is due to the abstraction of oxygen. It plays an important part in the chemistry of plant life, but it is not so common in the animal body. Fats may be formed from carbo-hydrates, as in the feeding of pigs with starchy matter; much more fat is formed than can be accounted for by the fat in the food. But fats presumably are formed from carbo-hydrates (starches, sugars, etc.), by the abstraction of oxygen. Not a few substances passed through the body suffer reduction. Thus the iodides and bromides of the alkalies are formed from iodates and bromates, and malic acid (as in fruits), becomes succinic acid.

(3) *Decompositions* frequently occur, when complex substances are split into simpler ones. Thus taurocholic acid, the acid of one

of the salts found in bile, taurocholate of soda, may be resolved into its two constituents, taurine and cholalic acid. Sometimes water is removed from a compound, and the remainder then decomposes. Thus creatin, a substance found in flesh-juice, by the abstraction of water becomes creatinin, which is voided in the urine. On the other hand there is a reverse process. Water may be first taken up in chemical combination, and a new substance then formed. Thus urea, found in the urine, combines with water, and there is then a re-formation of the molecules to form carbonate of ammonia.

(4) Living matter, in certain circumstances, may combine with oxygen, and possibly with other bodies, not by a chemical combination, but by a physical process depending on temperature and pressure. This has not been absolutely proved with protoplasm, but it is suspected. The colouring matter of the red blood corpuscle, a highly complex substance called haemoglobin, combines with oxygen to form a compound known as oxyhaemoglobin. The amount of oxygen taken

up varies directly as the pressure and inversely as the temperature. Thus, at the same temperature, by lowering the pressure by placing the oxy-haemoglobin in the partial vacuum of an air pump, the compound gives off the oxygen, without itself suffering decomposition. When the pressure is raised, the oxy-haemoglobin again takes up oxygen. This process, known as *dissociation*, depends on physical conditions. It plays an important part in respiration.

(5) By *synthesis* is meant the building up of complex chemical substances by the union of simpler bodies. This has been accomplished by the chemist, and, as already stated, numerous organic bodies have been formed artificially in the laboratory, such are urea, hippuric acid, glycine, taurin, creatin, glucose, and numerous organic acids, such as oxalic, lactic, succinic, benzoic, propionic, acetic, and formic acids. Even bodies resembling proteins have recently been formed synthetically, and it is probable that, by following out synthetic processes that are suggested by theory, proteins of

higher complexity may yet be formed. It is not easy to give examples of syntheses in the animal body. If benzoic acid is given in food or as a drug, it unites with glycine, probably in the liver, to form hippuric acid, with the elimination of a molecule of water. Many organic acids may thus be built up. Thus aromatic bodies unite with sulphuric acid, and conjugated sulpho-acids thus formed are eliminated by the kidneys. No doubt synthetic processes may also build up fatty phosphorized substances existing in nervous matter, haemoglobin (the colouring matter of the red corpuscles), and even proteins.

(6) *Enzyme* or *Ferment Action*. One of the most interesting chapters in the history of scientific discovery has been that of the nature of fermentation. Fermentation and putrefaction have been known from early times, but their true nature has been discovered only in comparatively recent years. It is now known that both are connected with the life-history of micro-organisms, such as in the ordinary fermentation of sugar into alcohol, carbonic acid, and other substances, by the agency of

various kinds of yeast cells or torulae, and the putrefaction of dead nitrogenous matter by the activity of various bacteria. A recognition of these facts, and of the part played by micro-organisms in many diseases, has led to the evolution of the vast realm of knowledge now known as bacteriology. Physiologists have long been acquainted with the existence in the body of ferments, such as the ptyalin of the saliva and the pepsin of the gastric juice, but it is only in recent years that there has been an adequate recognition of the part played by ferments in many physiological processes. It is now known that all ferments, or *enzymes*, as they are now called, are formed in the interior of cells. For a long time it was held that the plant known as the yeast cell effected fermentation in the juice of the grape or in a solution of sugar by its vital activity, and this view was favoured by the fact that during fermentation there was a remarkable multiplication of the cells of the yeast It is now known, however, that even this fermentation is caused by an enzyme (*zymase*) formed in the interior of the yeast cell.

In a similar way all enzymes are formed in cells, as, for example, ptyalin in certain cells of the salivary glands, and pepsin in certain cells in the tubular glands in the mucous membrane lining the stomach.

32. The enzyme, however, is preceded in the cell by an enzyme-forming substance, a *zymogen*, as it is called, and while the cell is secreting, matter appears in the form of small granules. Thus ptyalin is preceded by ptyalinogen, pepsin by pepsinogen, and so on. It would appear that just when the secretion is poured out the zymogen is changed into the enzyme, and the enzyme at once begins to act. Each enzyme has a limited field of activity. Thus three are required to modify the three varieties of di-saccharides, cane sugar, milk sugar (lactose) and maltose, one and only one for each sugar. The activity of enzyme is greatest at about 40° C : at about 50° C. the ferment is destroyed Extreme cold arrests the activity, but it does not appear to injure it, as it will again act at, say, 40° C. One remarkable feature of the action of an enzyme is that only a small amount is neces-

sary, and at the end of the process the amount of enzyme is the same as at the beginning If the enzyme is used up, or if a portion of it is used up, there must be a process by which the enzyme is reconstructed. To avoid this difficulty, it has been supposed that the enzyme acts catalytically, that is, merely by its presence. It is difficult to imagine that any substance can modify a chemical product merely by its presence. This idea arose from the fact that the enzyme appeared to be unaltered in the process. The chemist is also aware of chemical processes influenced by the presence of inorganic substances. Thus a mixture of oxygen and hydrogen immediately explodes when brought into contact with platinum black. If so, we may imagine that some kind of vibratory action is communicated to the molecules of the fermentable matter from the enzyme, and that this vibration causes the change in the substance The analogy is that of sympathetic vibrations between two tuning forks of the same pitch. Thus a fork Ut_4 will, if caused to vibrate by bowing, at once set in action the prongs of another fork, also Ut_4, even if the two forks are at a considerable distance from each other As we know nothing of the chemical constitution of enzymes, except that they are proteins, this can only be a conjecture, but it is to be borne in mind that proteins are very unstable. Enzymes may act alone or they may apparently be stimulated by other enzymes or by the presence of other substances. In chemical reactions we have to consider the element of time, or what we may term the velocity of the reaction. It would appear that all so-called catalytic actions, including the action of enzymes, have the effect of quickening the velocity of the chemical changes involved.

33. As already pointed out, enzymes are formed in cells. Cells may be frozen and then pounded into a paste. Enzymes are thus set free, and at the proper temperature they will manifest their usual activities. This shows that they do not depend on the life of the cells. There can be no doubt that as almost all cells contain enzymes, they take part in nutritional processes, by exciting changes in

the protoplasm of the cell, or possibly in the substances stored in the cell. They may thus carry on metabolic changes, during the life of the cell, and they may even cause destruction of the cell after death, by a kind of auto-digestion, or autolysis.

34. Most enzymes are hydrolytic, that is to say, we may represent their action by the addition of water to the fermentable matter and then a decomposition. Thus cane sugar plus water plus the enzyme, is changed into dextrose and levulose, two other varieties of sugar. But other enzymes are believed to carry oxygen to the tissues. These have probably to do with respiratory processes. They are termed *oxidases*.

35. Enzymes may be readily classified thus :—

(1) *Amylolytic*—Change polysaccharides such as starch into sugar. *Example: Ptyalin* of saliva and the *diastase* of plants.

(2) *Invertins*—Change disaccharides into mono-saccharides. *Ex.: Invertase* of intestinal juice, which changes cane sugar into dextrose and levulose.

(3) *Steatolytic or Lipolytic*—Decompose fats into fatty acids and glycerine. *Ex.: Steapsin* or *Lipase* of pancreatic juice.

(4) *Proteolytic*—Change proteins into proteoses, peptones, polypeptides, and at last into amino-acids. *Ex.: Pepsin* of gastric juice; trypsin of pancreatic juice.

(5) *Peptolytic*—Decompose proteoses and peptones into polypeptides and amino-acids. *Ex.: Erepsin* of intestinal juice.

(6) *Blood ferments*—Cause clotting of blood. *Ex.: Thrombin* (fibrin ferment); *rennin* of gastric juice converts caseinogen of milk into casein.

(7) *Ferment of ferments*—Enzyme that stimulates the formation and action of the trypsin of the pancreatic juice. *Ex: Enterokinase* of duodenum.

(8) The acid chyme, when it leaves the stomach, leads to the formation of an enzyme, *secretin*, which is absorbed into the blood and stimulates the secretion of pancreatic juice. Probably other chemical substances act in a similar way, on various secretions. These are called *hormones*

36. *Matter and Energy.* All chemical phenomena are associated with changes in energy, one of the great conceptions of modern physical science. Energy may be latent or locked up in a chemical substance, and it is then said to be potential. Thus, take any oil as an example. An oil contains carbon, hydrogen and oxygen so united as to form a complex substance, say the olein of olive oil, each molecule of which has a definite chemical composition. The oil (or the olein), however, is conceived to be associated with energy in a latent state, that is to say, the energy that binds the atoms into its molecule is there locked up, and so long as it is so, the molecule is chemically inert. But if it be oxidized, that is if it be burned in a suitable contrivance, say a lamp, the oxygen of the air unites with the carbon of the oil to form carbonic acid, and with the hydrogen, to form steam or water. The carbon appears in the form of soot. But during the burning, energy appears as heat, and the heat, by a suitable machine, might be converted into motion, and do work by lifting a weight and overcoming the

friction of a train of wheels. While the energy is thus doing work it is said to be actual or *kinetic.* The complete combustion of a given amount of olein would produce a certain equivalent of heat, and the heat, again, might be transformed into a certain equivalent of motion. There is a fixed quantitative relation between the two modes of energy. Thus physical science tells us that a unit of heat is the amount of heat that is required to raise the temperature of 1 gramme (15.4324 grains) from 15° to 16° centigrade, and the unit of work is the grammetre, or the amount of work expended in lifting 1 gramme to the height of 1 metre (39.37 inches). Apply this to a special case; a decomposition liberating heat, develops 1 heat unit, and this heat, if it does mechanical work, will perform 424 grammetres of work. Thus 1 unit of work may be converted into 1 unit of heat, and conversely.

37. Energy therefore may be either potential or kinetic. When simple substances are combined to form complex ones, energy becomes latent or potential, and when a complex substance is split up into simpler

ones energy becomes kinetic; it may appear, for example, as heat or motion. In the case we are considering, it is possible to determine with accuracy the energy the oil contains, or, in other words, the heat produced by its combustion; this amount of heat is conceived as kinetic energy; and if it were possible, by a synthetic process, so to combine the carbon, hydrogen, and oxygen as to re-form the olein, the same amount of energy would have to be expended as was liberated by decomposition. In any such system of operations the sum of the energy at the close would be the same as at the beginning.

38. *Chemical Substances.* We are now in a position to consider from the chemical point of view, the *matter* of which the body is composed. The chemical elements in living matter have been referred to in section 7. These elements are combined to form chemical compounds, divided into organic and inorganic. Organic compounds are again classified into nitrogenous and non-nitrogenous. The nitrogenous are the more important; they are necessary for the constitution of

protoplasm. It must be observed that a chemical analysis of living matter is not possible, because, in the processes to which it must be subjected, the condition we associate with life disappears. The living matter is killed by the attempt at analysis, so that what we are able to analyse is dead matter that was once alive. Suppose a chemist is asked to reveal to us the chemical constituents of a muscle, he might be able to enumerate the *elements* of which it was composed. This would teach us very little. But during the analysis it would be found that numerous more or less complicated chemical substances appeared, and that these could be arranged into groups, the members of which showed certain characters in common. In this way we learn that organic matter is built up of certain compounds called *proximate constituents*, or *principles*, already referred to These are proteins, carbo-hydrates, and fats, and along with these we find many other substances which are derivatives of these three, along with various saline substances and water.

39. The *proteins* are bodies of highly

complex chemical constitution. They all contain about 16 per cent. of nitrogen, along with carbon (more than half their weight), hydrogen, oxygen, and usually a small amount of sulphur or phosphorus, or both. Proteins, a typical example of which we find in the albumen in white of egg, are essential in protoplasm, and they are more intimately associated with the phenomena of life than any of the other proximate principles, in the sense that we never find vital phenomena without them, and that vital phenomena are never manifested by carbo-hydrates, fats, saline matter, or water, either alone or in combination. Proteins are usually colloidal or glue-like, and are non-diffusible through animal membranes. A colloid does not form a true solution, but in a fluid it forms a kind of emulsion consisting of minute particles or globules suspended in the fluid. (Such an emulsion-colloid is termed a *gel,* but there are colloids, having much finer particles, and which have different properties. Such are called *sols.* Protoplasm, alive, is probably of the nature of a sol.)

Of the true chemical structure of proteins we know little, but it has been shown that by various agencies they split up into numerous simpler bodies which also may be arranged in groups. There seem, as it were, to be lines of cleavage, so that the complex proteins, under the influence of acids, alkalies, high temperatures, and various enzymes, decompose into acids, bodies of a fatty nature, aromatic bodies,—which all contain nitrogen,—and bodies that belong to the carbohydrate group,—containing no nitrogen,—such as starch and sugar. Such bodies are produced when proteins are split up, whether it be by the processes of the chemist in the laboratory, in the process of digestion under the action of the digestive enzymes, or in putrefaction as carried on by many micro-organisms, and more especially by the *Bacterium termo*, a minute organism found wherever there is decay. Proteins are ultimately resolved into certain ammoniacal compounds and urea, a substance abundant in the urine.

40. The *carbo-hydrates* are the starches

and sugars. They consist of carbon, hydrogen and oxygen, the two latter elements being in the proportions that form water, that is two of hydrogen to one of oxygen, hence the somewhat inappropriate name. They contain no nitrogen. They are usually classified into the polysaccharides, such as starch and glycogen (an animal starch found in the liver), monosaccharides, such as dextrose, glucose or grape sugar; and disaccharides, such as cane sugar, lactose, and maltose. When cane sugar is inverted, it takes up water and is changed into equal parts of dextrose (grape sugar) and levulose (fructose). By hydrolysis of starch various forms of dextrin are formed. Cellulose, as found in the cell-walls of plants, is also a carbo-hydrate. Carbo-hydrates, by various chemical agencies, may also be resolved into simple substances, and ultimately into carbonic acid and water.

41. The *Fats* consist of a combination of a fatty acid and glycerine. They consist of carbon, hydrogen, and oxygen, but the amount of carbon present in proportion to the oxygen present is much greater than in carbo-

hydrates. When oxidized, as by burning, they are resolved into carbonic acid and water, with a great evolution of heat. The chief fats are tri-stearin, tri-palmitin, and tri-olein. When a fat is acted on by lipase (an enzyme), it hydrolyses and splits into a fatty acid and glycerine. If a fat is acted on by an alkali a soap is formed and glycerine is liberated.

42. Along with proteins, carbo-hydrates, and fats, there are various *salts*, such as chloride of sodium (common salt), chloride of potassium, various phosphates of soda, potash, lime, and magnesia. In the ash of organic matters we also find sulphur and iron compounds, but these are derived not from inorganic compounds of these elements, but from decomposition of the proteins It is doubtful if any of these inorganic salts exist during life in a free state ; it is more than probable that they are usually combined with organic bodies, and that in this way they take their part in vital phenomena. The proportions of the various salts, as determined by chemical analysis, is very uncertain. It may be that certain saline matters are simply dissolved in the colloidal

living matter. There is, however, another way in which they may be taken up, when they are not dissolved, but pass into the colloidal matter in virtue of some affinity for it. This process is called *adsorption.* The electrical state of the colloid influences this process. Adsorption plays an important part in physiological processes.

43. Finally we have *water*, the general solvent, and the medium by which the molecules of the other bodies are brought so close together as to permit of those reciprocal actions on which life depends. About two-thirds of the weight of the body consists of water.

44. *Chemical Phenomena of Plant Life.* We can now form some conception of the relation of matter and energy in the living body, and we shall be assisted if we consider the chemical phenomena of plant life and contrast these with what happens in an animal. A plant requires ammoniacal salts, water and carbonic acid. These it derives from the soil and the air, and ammoniacal compounds that are mainly the result of chemical

operations in the animal body. The protoplasm of the plant combines these with oxygen, forming more complex chemical compounds. Thus by means of chlorophyll, and under the action of the energy of light, it decomposes the carbonic acid of the air, retaining the carbon and returning the oxygen to the air. The carbon is then united with oxygen and hydrogen to form starchy substances, which, by the action of an amylolytic ferment (diastase), may be changed into sugars. In a similar way, the ammoniacal bodies are used up to form proteins. All this is done by the protoplasm of the plant cell, and there can be little doubt that the formation of these bodies is the result of chemical operations in the protoplasm, which is alive. To do this it must have oxygen, and it must get rid of the waste body, carbonic acid. This constitutes the true respiration of a plant, and must not be confused with the chlorophyll action above referred to. The plant thus transforms the kinetic energy of the sun's rays into the potential energy stored up in the starch and in the protein matter in its cells. Fats may also be formed. The plant protoplasm, however, while it performs this operation, also, in connection with its own special activities, sets free kinetic energy. Thus certain of the parts of plants produce heat, and energy may appear as motion, when rootlets press through the soil, or when certain parts move. Still the main relation of plant life to energy is that it stores it up, or *renders it potential.*

45. *Chemical Phenomena of Animal Life.* The activities of an animal are mainly of an opposite kind. The animal lives on plants or upon the tissues of other animals. Animal protoplasm cannot exist on ammoniacal compounds, water, and saline matters alone. It has little or no power of forming those into more complex substances. But it takes proteins, carbo-hydrates, and fats, and along with saline matters and water it builds these up into its own protoplasm. It may possibly use them to some extent directly, that is to say, without incorporation into its protoplasm, but this is doubtful. It is probable that there is a true incorporation, but, before incorporation, the

proteins, carbo-hydrates, and fats must be modified by digestive processes. So far the animal protoplasm, like that of the plant, has been storing energy There is now a reversal of the operation Under various stimuli, which may be the nervous impulse, or a mechanical, thermal, or electrical stimulation, the protoplasm either contracts (as in muscle) or is the seat of chemical operations (as in a secreting cell or an electrical organ), and energy is set free as motion and heat, or, it may be, luminous or electrical energy This implies decompositions and oxidations, and requires oxygen from the air. The splitting up of the complex protoplasm causes the formation of simpler bodies. These may be again and again further oxidized into simpler compounds, always with the evolution of energy, as heat, until ultimately we reach simple ammonia-like bodies, urea, and water. *Thus the protoplasm of animal cells is chiefly engaged in the liberation of potential into kinetic energy.* Both plant and animal take part in both processes. In the plant there are oxidations as well as reductions, but mainly reductions; in the animal there are reductions as well as oxidations, but mainly the latter. Both, as in processes of development, convert potential into kinetic energy, but in the plant the conversion is mainly from kinetic into potential, while in the animal the action is far and away a passage from potential into kinetic energy. *Thus the plant world is, physiologically, the complement of the animal world*

CHAPTER VII

INCOME OF MATTER. THE ABSORPTION OF FOOD STUFFS

46. As all forms of vital activity cause a certain amount of tear and wear owing to the breaking down of living matter, or, in other words, the decomposition of complex organic substances into simpler ones,—usually accompanied either with the withdrawal of oxygen (reductions) or with the union of oxygen with oxidizable substances (oxidations),—matter must be supplied in the form of *food*. Food stuffs however, as a rule, are very unlike the tissues of the body. Observation also shows that animals may live on food stuffs that are very unlike in appearance. Thus an ox can live upon grass, a horse on hay and oats, a rabbit on turnips or carrots, a tiger and other flesh-eating animals on flesh of various kinds. Man is so constituted as to find a mixed diet

most suitable. All mammals begin their existence on milk. The tissues of a chick are built up out of materials contained within an egg. If, however, we analyze food stuffs, or diets that are known from experience to suit all dietetic requirements, we find they always contain representatives of the five proximate constituents found in the tissues of the body, and which we have considered. Thus a suitable dietary for almost any animal, and certainly for men, always contains proteins, carbo-hydrates, fats, saline matters and water. Other substances, such as the condiments that are often added, are merely adjuncts to the diet. Thus milk contains more than one protein substance, the chief one being caseinogen, which yields, when acid or rennin is added to the milk, a protein, casein, the chief constituent of curd; a carbo-hydrate as sugar of milk; a fat, or rather several fatty matters that all together form butter; various salts (chiefly chloride of sodium and phosphate of lime); and water. These proximate constituents are found in varying amounts in different articles of food met with in dietaries. Thus, butcher meat abounds in protein and fat, potatoes in starch (a carbo-hydrate); and vegetable oils and animal fat are rich in fat. By combinations of these, a suitable dietary is formed, and experience has taught mankind, even in savage conditions, empirically to combine such substances. Further, science has shown that a suitable dietary supplies the requisite amount of carbon and the requisite amount of nitrogen to make up for the daily loss of carbon eliminated chiefly by the lungs, as carbonic acid, and of nitrogen thrown out by the kidneys mainly as urea.

47. In order to become incorporated with the living tissues, food stuffs must pass through a series of elaborate physical and chemical processes, the object of which is to render them soluble and suitable for absorption into the blood. These processes constitute *Digestion*. The food is broken down and mixed in the mouth with saliva so as to form a pulpy mass. Such matters as saline substances may be at once dissolved, and the whole process is facilitated by the

heat of the mouth. *Mastication* is a physical process carried on by the movements of the jaws bearing the teeth. Saliva is a fluid poured forth from *three pairs of salivary glands* and by numerous small glands in the membrane lining the various parts of the mouth. Chemically, the saliva acts only on carbo-hydrates in the form of starch: it has no chemical action on proteins or fats. The saliva, in addition to being a watery solvent, contains an enzyme called *ptyalin*, which converts starch into dextrose or grape sugar, thus rendering the carbo-hydrate soluble. The saliva also lubricates the mouthful with mucus, and thus facilitates swallowing.

48. The food is then swallowed (*Deglutition*) and by a muscular mechanism (controlled by nerves) it is prevented from escaping by the mouth, or into the nose by the posterior apertures of the nostrils, or into the chink between the true vocal cords which is the entrance into the trachea, or windpipe, and the respiratory passages. It is propelled into the gullet (*oesophagus*), and carried into the stomach by a series of contractile move-

ments. The greater part of this nervo-muscular mechanism is beyond the control of the will, after the food has passed sufficiently far into the mouth, and so exquisite are its adaptations that only when food is swallowed hurriedly, or with great gulps of liquid, is there any danger of the matter entering the wrong passage.

49. In the *stomach*, which is simply a special enlargement of the alimentary canal, the food is subjected to three processes:—(1) The action of a temperature of about 98° F.; (2) a churning-like motion produced by slow contractions of the muscular walls by which the food is thoroughly mixed with the special secretion of the stomach, the gastric juice; and (3), the chemical action of the *gastric juice* itself. This juice is secreted by numerous tubular glands in the mucous membrane, It is a clear watery fluid containing a minute quantity of various salts in solution, a small amount (·2 per cent.) of hydrochloric acid, and a special enzyme, *pepsin*. It is only secreted in ordinary circumstances when food enters the stomach, and by the contractions

of the walls it is thoroughly mixed with the contents. The action of pepsin is on proteins, converting these into a more specialized form of protein, termed *peptone*; and in this action it is assisted by the free hydrochloric acid of the gastric juice. The juice, by acting on the walls of the cells in the food stuffs, liberates fatty matters, or granules of more or less cooked starch, and thus these are prepared for further digestion. Saline matters, that may have escaped the solvent action of the saliva, are dissolved. Protein food stuffs, as in cooked butcher meat, are disintegrated into fibres and small morsels; these are then acted on by the pepsin and hydrochloric acid. The result is the formation of a semi-digested mass, the *chyme*, which, as it is formed, escapes through the pyloric opening into the first portion of the small intestine, the duodenum. During the digestive process in the stomach, the orifices at the lower end of the oesophagus and at the beginning of the small intestine, the pyloric opening, are tightly closed by sphincters. Thus a portion of any protein in the food is converted into simpler and more soluble forms of protein called *peptones*, and the mass, containing, in addition to peptones, undigested protein matters, sugars, starch-granules that have escaped the action of the saliva, fats in a more or less fluid state, salts in solution, constitutes the *chyme*. It is doubtful if absorption to any extent occurs in the stomach. The free hydrochloric acid of the juice may cause some proteins to swell and become gelatinous-looking, forming what is called *syntonin*. The acid also, to some extent, destroys bacteria that are almost inevitably swallowed with the food, but many escape into the bowel. The gastric juice of young mammals also contain *rennin*, a milk-curdling enzyme. *Thus the special action of the gastric juice is on proteins.*

50. *The Intestine.* The chyme is propelled into the small intestine, which is of great length; in it two processes occur: (1) the completion of digestion, and (2) the absorption of digested matters. Near the beginning of the small intestine, in the duodenum, two fluids mix with the chyme, the *bile*, formed

by the liver, and the *pancreatic juice*, secreted by a gland similar in structure to the salivary glands, called the pancreas. The bile is constantly being formed by the liver, and passes drop by drop from the end of the bile-duct into the duodenum. This fluid does not take an active part in the digestion of the constituents of food, and it may be regarded more as an excretion or waste product of the complicated chemical processes occurring in the liver. Still, as it is poured into the small bowel so near its beginning, it must exert some influence. That influence may or may not be beneficial according to its quantity. If in great amount it may pass back into the stomach and partly arrest the digestive process there, as happens in a bilious attack; or it may to some extent interfere with processes in the bowel if in excessive amount, and it appears to act as a stimulant to the musculo-nervous mechanism of the bowel by which the chyme is propelled onwards. In excess it may cause diarrhœa. A portion of the bile may be stored in the gall bladder, an organ, however, that does not appear to be indispensable, as many animals have no such reservoir.

Along with the bile from the liver, the *pancreatic fluid* enters, often by a duct formed by the confluence of the ducts of the two glands This fluid is secreted only during the digestive process, and the secretion appears to be stimulated and modified in character by a special enzyme in the duodenum called *secretin*, a remarkable example of a ferment body acting so as to excite the activity of another enzyme-forming gland. Another enzyme, known as *entero-kinase*, formed in the duodenum, appears to facilitate the action of one of the pancreatic ferments, trypsin The pancreatic fluid is assumed to contain three ferments: (1) one acting on proteins and peptones, called trypsin, splitting those up into simpler bodies, mainly such as leucin and tyrosin (crystallizable bodies); (2) another, *amylopsin*, acting on the starch, cooked or raw, which has escaped the saliva, changing it into grape sugar; and (3) one that acts on fats, *lipase*, splitting them up into glycerine and a fatty acid, while the free acid immediately unites with alkalies in the bowel, potash and soda, to form highly soluble *soaps*. The pancreatic juice also contains a milk-curdling ferment. The action on proteins is to split up the protein molecule into simpler soluble substances, such as leucin, tyrosin, and simpler bodies known as amino-acids. Some of the bodies so formed may be absorbed into the blood, while any excess is probably voided in the faeces.

51. The whole length of the small intestine contains numerous glands, those in the duodenum termed the glands of Brunner, while the others are known as Lieberkuhn's glands. These glands secrete the intestinal juice, which has a feeble action somewhat resembling that of the pancreas. It contains a special enzyme, *erepsin*. (See p. 76.) There is also present an enzyme called *invertase*, which splits up cane sugar into dextrose and levulose.

52. The *great intestine*, which is much shorter and wider than the small, may be regarded as a receptacle for the refuse materials of food stuffs that have not been

digested, and for various substances excreted by numerous tubular glands. The secretions of the great bowel do not take an active part in true digestion. Putrefactive processes also are carried on, even in the small bowel, and still more in the larger bowel, and these processes, due to the activities of numerous bacteria, still further split up the protein molecules, with the production of offensive smelling bodies, indol, skatol, phenol, etc. These bodies, by uniting with sulphuric acid arising from sulphates (originating from the sulphur of proteins), form etherial sulphates, such as indoxyl-sulphate of potassium This body is called indican, and is voided in the urine. Such fermentative and putrefactive processes, all due to specific organisms, also attack carbo-hydrates and fats, producing lactic acid, butyric acid, sulphuretted hydrogen, carbonic acid, and other substances. The absorption of these may cause a kind of auto-poisoning of the individual.

53. It will be seen that all the constituents of food are now soluble and ready for *absorption.* This is accomplished mainly in the

small intestine, partly by the blood vessels, and partly by special absorbents, the *lacteals.* Covering the whole of the mucous membrane of the small bowel there are innumerable small finger-like processes, like the pile of velvet. Each process is a little organ called a *villus.* In the centre of each villus there is a tube, the outer end of which communicates with numerous minute channels; this is the commencement of the absorbent system. By the confluence of the bases of these tubes a network of fine tubes, running in the mesentery (or web connecting the bowel with the wall of the abdomen) is formed, and these tubes, by confluence, form larger and larger tubes until they reach certain gland-like structures, the *mesenteric glands.* The ducts of these glands, now called *mesenteric lymphatic glands*, pass to a special receptacle, the *receptaculum chyli*, and from it a large duct, the *thoracic duct,* runs up through the thorax, and, at the root of the neck, on the left side, opens obliquely into the venous system, just at the confluence of the internal jugular vein, carrying blood from the head and neck, with the superior subclavian vein, coming from the left arm. This *lacteal system* (so called because, during the digestion of fat, it is filled with a milky like fluid, the *chyle*) is the absorbent system mainly for fats, taken up, either as a fine emulsion or as soaps, from the bowel by the villi.

54. In each villus, between its epithelial covering and the centre, in addition to the fine absorbents already noticed, there is a rich plexus of capillary blood vessels. These absorb all soluble matters, such as peptones, sugars, possibly soaps, saline matters, water, and any other substances in solution. The blood thus circulating in the villi is gathered up by veins, and these form the *mesenteric system of vessels.* Blood is thus gathered from all parts of the intestinal canal, stomach, small intestine, and large intestine, and by the vessels forming the *portal system* and, by a large vein called the *portal vein,* it is carried to the liver. It will thus be seen that all the products of digestion, except emulsive fats, and *all soluble matters,*

are in the first instance carried to the liver. In that organ, the largest gland in the body, and the seat of intense physiological activities, intricate chemical processes occur. One of the results of these is the formation of bile, which may be regarded as a waste product arising from the chemical processes occurring in the gland. The blood, laden with matters absorbed from the alimentary canal, and modified by the cells in the liver, issues from the organ by the *hepatic vein*, which then pours the blood into the venous system. The matters thrown out in the bile will be considered in connection with excretion.

Thus it will be seen that all the matters absorbed in the alimentary canal ultimately reach the venous system. *They all contribute to the making of blood.* The fatty matters absorbed by the villi are modified by the mesenteric glands. They feed the protoplasm of these glands, which then gives off leucocytes or colourless corpuscles. These glands are abdominal lymphatic glands, and they share with other lymphatic glands (found in many parts of the body) in the production of leucocytes. Finally, matters that are undigested; chemical substances arising from proteins that have not been absorbed; special matters secreted by the glands of the great intestine of which we know little; countless bacteria; and earthy matters, such as phosphates of lime and magnesia,—are voided in the faeces.

55 There are several interesting questions as to absorption that must be noticed, as an answer to them takes us to first principles. Water and soluble salts are absorbed unchanged. The salts may be adsorbed. Carbohydrates are all absorbed as sugars, and they are carried to the liver and are there transformed into glycogen (a kind of animal starchy substance), and stored for a time No doubt some may pass along in the blood stream, and be at once used by the tissues. It is highly probable that when no fresh sugar is coming from the intestine sugar is supplied from the liver to the tissues, that is to say glycogen is changed by a liver enzyme into sugar, and this is at once washed away. There are good grounds

for the view that leucocytes take some part in these processes, as we find always a great increase of these cells during absorption. Fat we have seen to be absorbed by the lacteals of the villi. Ultimately the molecules of fat reach the protoplasm in lymphatic glands, and are there changed; but probably a portion of the fat is seized by special cells in connective tissue (fat cells), and is stored there in a liquid state. How it is used up by the tissues is still obscure, but we may be sure it contributes to the making of protoplasm in muscular, and more especially in nervous, tissues.

It is also difficult fully to explain the changes that happen in proteins. At one time it was supposed that peptones were absorbed as such, and thus entered the portal circulation. This view has been abandoned, and now it would appear that protein matter is absorbed in simpler forms than peptones, and especially as amino-acids. These are acids belonging to the group known to chemists as fatty acids, substitution compounds in which one of the hydrogens of the radicle is replaced by a molecule containing two atoms of hydrogen and one of nitrogen. Thus take caproic acid, one of the fatty acid series. It is represented by the chemical formula $C_5H_{11}.COOH$; substitute for one of H_{11} a group NH_2, and we have $C_5H_{10}.NH_2.COOH$, or amino-caproic acid, a well-known body called leucin. It is important to note that these amino-acids, of which there is a large number known to chemists, are always among the final products of the decomposition of proteins. Hence it was inferred that proteins were absorbed as amino-acids. These, however, have not been found in the blood, possibly owing to great technical difficulties, and it is still a matter undecided as to (1) whether proteins are so absorbed, and (2) how and where they are re-transformed into the proteins of the blood. It is a fact, however, that they all pass to the liver, and that during the absorption of proteins the nitrogen in the blood increases.

Further, it would seem that protein matter may be used up in two ways. A certain portion in the blood is carried to the tissues, and there it is metabolized for the upbuilding of protoplasm. As we now know there are many tissue-enzymes, it may be that in the living cell these enzymes, in a sense, re-digest this portion of proteid, changing it again into amino-acid bodies, and that these are used for upbuilding protoplasm. But there may be an excess of protein, and it may then be thrown aside as creatin and other bodies found in muscle-juice. This portion we may call *tissue-protein.* Probably it has characters of its own different from those of the other portion of the protein which we must now consider. This second portion of protein, which we may term *excess-protein,* is decomposed by cells in the liver, passes probably through many stages and is ultimately voided by the kidneys in the form of urea. A rich protein diet always causes an increase in the amount of urea eliminated. There are, however, critical objections to this view. Is this complicated process merely an arrangement for getting rid of excess of protein? One can hardly imagine this to be the case. At present we are not yet in a position to state what occurs in a hepatic cell. The process may not be a series of processes,—one having to do with the storage of glycogen, another with the making of substances in the bile, such as bile pigments, bile salts, cholesterin, etc.,—but one synthesis and one decomposition.

CHAPTER VIII

THE BLOOD. ITS RELATION TO THE LIVING TISSUES

56. We have seen that the various food stuffs rendered soluble by the processes of digestion are taken into the *blood*. This fluid is brought by the smaller vessels, the capillaries, into close proximity to all the elements of the living tissues. From the blood vessels a fluid passes out through their walls and permeates all the tissues, bathing their elements, so that there is much truth in the aphorism that the elements of the living tissues, and more especially the living cells, live like aquatic organisms, that is to say, they live in a fluid, and their lives and activities depend on interchanges between them and the fluid. This fluid is the *lymph*. Some of it is used up in the nutrition of the tissues, and the surplusage, now containing in solution matters derived

from the breaking up of substances in the tissues—substances derived from their physiological tear and wear—is carried off by a drainage system of tubes, the *lymphatics*. The lymph, however, is not thrown out of the body as useless, but, as in the economy of a well-arranged manufactory, it is utilized; it is carried to *lymphatic glands* found in many parts of the body and of the same class as those already alluded to as existing in the mesentery. By these glands it is used up, elaborated, as is often said, so as to nourish the protoplasm of those organs, and it is ultimately poured into the blood, either along with the chyle in the thoracic duct, or by a special duct, the *lymphatic duct*, which joins the venous system at the root of the neck on the right side. Thus the blood receives all the lymph and all the chyle. It also receives cellular elements from the lymphatic glands, from the kind of tissue called *lymphoid* or *adenoid* tissue, found in many organs and beneath many mucous membranes, and, in particular, from the *red marrow* found in the cavities in the bones. It also receives oxygen from the air by the process of respiration. The blood also receives matters that may be absorbed from many surfaces, both internal and external, such as the pleural and peritoneal cavities. The blood is therefore a highly complex fluid. It must be regarded not so much as a fluid as a complex tissue, and as the physical condition of its cellular constituents, the blood corpuscles, as well as the nutrition of the tissues to which it supplies lymph, depends on it, we find that it varies very little either in its physical characters or in its chemical constitution. Thus its specific gravity and its viscosity vary within very narrow limits. Matters coming to it by the channels above indicated are constantly being used up by the tissues; so that, although a considerable amount of these matters enters the blood daily, the percentage amount of any one of them is, as a rule, small. Again, matters that are waste products—and which would be injurious to living tissues, if they accumulated above a small percentage—are continually being eliminated by various excreting organs. *Thus the blood does not vary much either in quantity or quality, a physiological condition of great importance.*

57. As already mentioned, the blood is a highly complex fluid. It contains three kinds of corpuscles, (1) red corpuscles, or *erythrocytes*, (2) white or colourless corpuscles, (*leucocytes*), of which there are several varieties; and (3) minute particles called *blood plates*. The red corpuscles, chiefly concerned in respiratory exchanges, exist in enormous numbers,—in human blood amounting to as much as five million in a drop of blood about one-twenty-fifth of an inch in diameter. The white cells probably perform several functions. They may imbibe certain matters from the fluid of the blood and elaborate these into other substances. By their power of spontaneous amoeboid movement they may seize upon and digest worn out effete red cells, or micro-organisms that in many diseases find their way into the blood.

58. Recent observations on the blood,

mostly by way of experiment, have shown that in the blood there are substances which are of physiological importance although their quantities may be so small as to be beyond our present methods of analysis. These bodies seem to act as chemical defensive agents against disease. It is well known that the leucocytes act as *phagocytes*, that is they seize, hold, and devour bacteria and other micro-organisms. But, in addition to this phagocytic action of leucocytes, the fluid of the blood contains substances that are bactericidal. These substances, probably protein in their character, are destroyed by heating the blood for an hour to 55° C. Possibly they are derived from leucocytes. They may be called *bacterio-lysins*. Other substances in the blood may have the power of destroying red corpuscles. Thus the blood serum of one animal has the power of dissolving the red corpuscles of another species. Such bodies are called *haemolysins*.

The importance of these bodies is now generally recognized. Bacteria or bacilli of many kinds, if they find entrance into the body, cause disease, either by multiplying in enormous numbers or by producing substances, called *toxins*, which act as poisons. A toxin is probably of the nature of a protein or proteose, and usually there is associated with it another body, called an *antitoxin*, sad to be of the nature of a globulin. Toxin and antitoxin neutralize each other, so that a mixture injected into an animal may produce no effect. By a system of inoculating a healthy horse with small but increasing doses of the diphtheria virus, the serum of the animal by and by contains a large amount of antitoxin, and the injection of this serum in a case of diphtheria may save life by neutralizing the toxin of the disease. Sera prepared in this way are now used in practical medicine with beneficial effects. Further, they may confer *immunity*, that is to say, the injection of such fluids may protect against attacks of the disease. Thus the body may be protected against the invasion of specific organisms by the phagocytic action of leucocytes, by the globulicidal action of various substances in the blood, and by the formation of antitoxin.

There may also be present in the blood substances called *agglutinins*, that arrest the movements of bacteria and throw them into masses or clumps, and in this condition they are more readily devoured by leucocytes. Lastly, there are substances known as *opsonins*, that also appear to increase the phagocytic power of leucocytes. The true nature of these chemical substances is unknown. They are probably proteins, but whether they are different substances or modifications of one substance s a question to be answered by further research. The history of this obscure subject is a striking illustration of the complexity of the physiological processes that may possibly occur in the blood.

59. The blood is rich in proteins, especially in the form of a variety of albumen and of a protein substance known as serum globulin or fibrinogen. It contains traces of many other substances. If we examine the blood as it circulates in the capillaries, under the microscope, we see that the fluid, *liquor sanguinis*, is an almost colourless fluid, and

that the corpuscles, in single file, are carried along by the stream. When shed, however, it quickly *coagulates*, that is it clots, and the clot, in a suitable vessel, is soon surrounded by and floats in a serum. This power of clotting no doubt is a salutary function, as when vessels have been accidentally cut, they are, as a rule, soon plugged by the clot, and bleeding ceases. Much investigation has been expended on the phenomenon of clotting, a process somewhat analogous to the clotting of milk when it sours, from the formation of lactic acid, or when acted on by the ferment of rennet. The milk separates into curd and whey; the blood separates into serum and clot. A clot consists of blood corpuscles and a substance called *fibrin.* If we place a piece of blood clot under a water tap, we can wash out the corpuscles and we obtain *fibrin* in the form of a yellowish fibrous material. It is evident that the formation of fibrin, which entangles the corpuscles in its fibrous meshes, produces a blood clot. There is, however, no fibrin in blood, but a substance called *fibrinogen.* The theory at present in vogue is that when blood is shed there is at once the death of many colourless cells. These contain a protein called *pro-thrombin,* which, in turn, produces an enzyme known as *thrombin,* and this ferment, in association with salts of lime, converts fibrinogen into fibrin. To account for the fact that blood rarely clots in living vessels, we may assume the existence of a body produced by the living cells lining the vessels which prevents thrombin from acting (an *anti-thrombin*). There is still uncertainty as to what precisely happens in the remarkable phenomenon of the clotting of blood, and there is little doubt that if it were thoroughly understood, light would be thrown on other physiological phenomena, as it may be taken as the type of a certain class of changes in living matter.

60. The blood is not only a nutritional medium but it is also intimately connected with respiration. The red cells, by the action of the pigment they contain, known as *haemoglobin,* are engaged in carrying oxygen to the tissues and also it would appear to some extent in the carrying of carbonic acid

from the tissues to the lungs, there to be eliminated.

61. In order that the blood may be brought into close proximity to the tissues, we find a system of tubes, the *organs of the circulation*, known as *arteries*, *capillaries*, and *veins*, and at one point of the circulation, where the arteries begin and the veins terminate, we find a contractile force-pump, the *heart*. The walls of the arteries near the heart are thick, strong, and highly elastic; in those farther away we find the elastic wall gradually becoming thinner, and a contractile wall of non-striated muscle appears, and becomes thicker as we pass onwards, until in the smaller arteries, or *arterioles*, the muscular coat is the most pronounced. The arteries terminate in the capillaries, which form a network of minute tubes, many having a diameter of not more than the three-thousandth of an inch. These capillary networks bring the blood close to the living tissue elements. Some tissues, and always those in which there is great physiological activity, are more vascular than others. The capillaries terminate in the

veins, thin walled vessels, which carry the blood back to the heart. The smaller veins, by their confluence, form larger and larger veins, and the large veins, in various situations, are furnished with valves which, when open, are directed towards the heart, and thus direct the flow of blood to that organ. The heart itself, in man, has four cavities, two auricles, a right and left, that receive blood, and two ventricles, right and left, that drive the blood out. The right auricle receives the blood from the peripheral parts of the body, and the left receives it from the lungs. The two auricles contract simultaneously. The two ventricles then simultaneously contract, the right driving the blood through the *pulmonary circulation*—arteries, pulmonary capillaries, veins—to the lungs, for respiratory purposes, while the left ventricle drives the blood through the *systemic circulation*,—arteries, capillaries, and veins,—through the body, so as to bring the highly oxygenated and nutritious blood to the tissues. Valves are placed at various orifices of the heart and they so work that the blood must flow in the required direction.

62. The hydraulic principles of the circulation are remarkable. Blood must flow from situations of higher pressure to situations of lower pressure. High pressure is kept up in the great arteries by the contractile action of the left ventricle of the heart acting like a force pump and, with each stroke of contraction, throwing blood into them, so that, in a sense, they are over-distended. During the intervals between the heart beats, the walls of the arteries recover themselves by the resiliency of their elastic coats. This distension and elastic recoil constitutes the *pulse*, which is a wave of motion along the walls of the arteries, starting from the heart, travelling onwards with a certain velocity, and becoming smaller and smaller until there is no pulse in the smallest vessels, the capillaries. In consequence also of the loss of energy by friction, and by the distension of the arterial coats, the movement of the blood becomes slower and slower until, in the capillaries, the blood is slowly meandering onwards

at a very low pressure. This is exactly the condition most favourable for the transudation of fluid through the thin walls of the capillaries for the nourishment of the living tissues. But there is another remarkable arrangement that suits two purposes: the muscular walls of the arterioles, by contracting, can vary the diameter of these small vessels. When the calibre is diminished, it will be evident that the blood will not pass through the small vessels so easily as it will do when the calibre is increased. The contractile arterioles act like a kind of stop-cock at one part of the system. When the stop-cock is open, as when the arterioles are dilated, the blood flows through easily, the arterial system empties quickly through the capillaries into the veins, and the pressure in the greater arteries falls. When the stop-cock is partly closed, the blood will meet with resistance, and the pressure in the larger arteries rises. Thus, as the arterioles are always partially contracted under the influence of special nerves, there is always a sufficiently high pressure in the arterial system to keep up the supply of blood to the capillary districts even between the heart beats. When the heart ceases to beat, as at death, the arterioles become at the same time widely dilated, the pulse disappears, and by the elastic recoil of the walls of the great arteries the blood passes through the capillaries into the veins. Hence, after death, in ordinary circumstances, the blood is found in the veins, while the heart and arteries are empty It will be seen, also, that the contractile coat of the arteries regulates the supply of blood to various capillary districts, according to their physiological necessities.

63. The movements of respiration also assist the circulation. During inspiration, when the chest is dilated, pressure is removed from the surface of the heart and of the great vessels springing from it ; these tend to dilate and thus the blood is as it were sucked towards the heart by the great veins and by the right auricle and right ventricle. During expiration there is increased pressure on the heart, more especially when expiration is forced, and the blood does not flow towards

the heart so easily. The flow of blood towards the heart is also favoured by muscular movements in the limbs pressing on the thin walled veins, and as these are provided with valves opening towards the heart, the blood must flow onwards. Pressure on the veins of the organs in the abdomen must also assist, and so great is the capacity of the circulatory system in the abdominal and pelvic cavities that a quantity of blood equal to all the blood in the body might be therein contained. If there is more blood in one part of the body there will be less in another. An adjustment of local circulations is constantly going on, according to the degree of physiological activity of one organ or another. If there is a large supply of blood to the abdominal viscera, as during digestion, or to the skin, as when exposed to heat, there will be less blood in other internal organs. This may in part account for the mental lethargy after a full meal, and for the lassitude one feels during hot weather.

64. The circulation of the blood is thus carried on in accordance with the physical laws

of hydraulics. We might imitate it roughly by elastic tubes and a force pump. We can drive water through the streets and houses of a town by a head of water or a powerful engine, but even with our present technical skill, we could not automatically regulate the supply according to the wants of different districts by using automatically working elastic and contractile pipes.

CHAPTER IX

THE OUTPUT OF WASTE MATTER

65. It has already been pointed out that the activities of the living tissues cause to some extent a breaking up of living matter, and the appearance of waste products. In addition to this, waste matters may arise from the using up by the protoplasm in cells of matters previously stored up in them. That is to say, there may be intracellular chemical changes excited by enzymes in stored matters, as well as chemical changes involving the protoplasm. Both of these varieties of chemical change may produce substances that are of no further use in the body, and may even be injurious if allowed to accumulate in the blood. Such matters are not allowed to accumulate: they are quickly removed so that only small percentages are usually found in the blood, and this fluid, as has already

been explained, is maintained in a state of nutritive equilibrium. The separation and elimination of waste matters are effected by the process termed *excretion*. A *secretion*, such as saliva, or gastric juice, is a fluid holding matters in solution which have been formed by the activities of the cells in secreting glands, and it is intended to be used for some other purpose in the economy of the living body. Reference has already been made to the uses of the saliva and of the gastric juice. An *excretion*, on the other hand, is the separation from the body of such a fluid as urine by the kidneys, or bile by the liver-fluids of no further use. The chief excretive mechanisms will now be considered.

66. *Lungs*. By the process of *respiration*, carbonic acid is excreted by the lungs. This substance, carbonic acid, is produced in connection with the activities of all living matter. It is formed in the tissues, especially in the glandular, nervous and muscular tissues; it is abundant in lymph; it exists in the blood in a state of loose chemico-physical combination with the potassium salts and

with the haemoglobin of the red cells. The lymph surrounding the living tissues is, as already explained, a respiratory as well as a nutritive medium. The living elements, in a sense, breathe in the lymph. They receive oxygen from it and they give up oxygen to it. The tension of the oxygen in lymph is high, whereas that of carbonic acid is low, as it is quickly removed. This facilitates the interchange of gases, which we may regard as an internal respiration. The lymph ultimately reaches the blood and carries the carbonic acid with it. Further, in the tissues themselves there is an absorption of carbonic acid by the small capillaries and veins. The blood thus becomes venous. It is carried away to the right side of the heart by the veins, from thence it passes by the pulmonary circulation to the lungs, and there the carbonic acid is got rid of into the air cells of the lungs, and, finally, it reaches the outer air in the air of expiration. How the carbonic acid passes out of the capillaries into the air cells has not yet been clearly made out. The tension of the carbonic acid in venous blood is greater than the tension of the gas in the air cells of the lung, and it may be supposed that this tension would drive off the carbonic acid. Still there are difficulties with regard to this purely physical explanation, and it may be that the cells found on the delicate wall between the blood and the air may exert selective action, and, in a manner analogous to true secretion, excrete the carbonic acid.

67. Respiration, however, is a double function. Not only is carbonic acid eliminated in the air cells of the lung, but oxygen is absorbed into the blood, and by the blood it is carried to the tissues. There can be no doubt the oxygen is taken up by the all important constituent of the red cells called *haemoglobin*. It combines to form a loose union with this pigment. The red corpuscles, laden with oxygen, are hurried to the tissues, and there a reverse process occurs. The oxygen leaves the oxy-haemoglobin probably in successive small quantities, passes into the lymph, and is at once taken up by the living tissues. In the air cells of the

lung the oxygen passes through the thin wall between the blood and the air possibly physically, inasmuch as the tension of the oxygen in the air cells, especially at the end of an inspiration, is greater than the tension of the oxygen in the blood,—but again various considerations lead us to suppose that the taking up of oxygen may be a vital process due to the activity of the cells lining the air cells and also lining the vessels. The air bladder of a fish is the representative of the lung; in many cases it contains a large percentage of oxygen, secreted from the blood of the fish by the epithelium lining the bladder. (It is remarkable, however, that in shallow water fishes the gas in the air bladder is chiefly nitrogen.) This oxygen was in the first instance separated from the water by the blood vessels of the gills as the water flowed over them. In the tissues, again, *internal respiration* may not be entirely a physical process, as we are dealing with living tissues. Here, again, there may be selection of living gases by living cells.

What we usually think of as respiration

is a series of muscular movements by which the chest expands, as in *inspiration*, and the air rushes into the upper air passages to mix with the air already there: this is followed in ordinary *expiration* by an elastic recoil of the chest wall by which the air is expelled from the upper air passages. The air in those passages mixes with the air in the ultimate air cells by a physical process of diffusion of gases. The whole of this process, the distension and recoil of both chest wall and lungs, constitutes a *pulmonary ventilation*. The essential phenomena of respiration are, however, in the air cells and in the tissues. The lungs may eliminate a small amount of water by evaporation from the respiratory gases, and, occasionally, other matters may pass off which taint the breath. The mechanism of external breathing is carried on by a complex system of muscles and by a special innervation.

68. *Kidneys*. Excretion is also carried on by the kidneys. These organs, which may be regarded as highly modified tubular glands, separate from the blood, water; various

saline matters, chiefly chloride of sodium (common salt) and phosphates of the alkalies (potash and soda), and of the alkaline earths (lime and magnesia); various nitrogenous substances, more especially urea, uric acid, creatinin, etc.; and pigmentary matter. The kidneys also take a slight part in the elimination of carbonic acid. These matters are separated from the blood mainly by the activity of the epithelial cells lining the uriniferous tubules. In the cortical part of the kidney there are remarkable structures known as the *Malpighian Bodies*, consisting of a glomerulus or ball formed by a network of capillaries, surrounded by the dilated end of a uriniferous tubule, so as to form a capsule lined by a peculiar form of epithelium. The end of the tubule is infolded over the capillary nodule so that a double wall surrounds the nodule. Thus a somewhat complex membrane is formed like a kind of cap, and three layers, blended together, separate the blood from the urine—namely, the wall of the capillaries and a double wall formed by the infolded end of the tubule. This was once supposed to orm a filtration apparatus by which the watery constituent of the urine, holding salts and other matters in solution, was filtered from the blood through the thin membrane nto the end of the tubule It would appear, however, that the process is not one of simple physical filtration. but that there is a selective action due to the vital activity of the epithelium. A minute vessel passes from the glomerulus or ball of capillaries, and this divides again into capillaries which ramify on the first portion of the uriniferous tubule. The epithelium in this portion is of a peculiar kind, and it has been thought that it has to do with the separation from the blood of nitrogenous matters. There is still considerable obscurity as to the precise mechanism by which urine is formed.

69. In a healthy man about fifty ounces are excreted daily. Its colour is due to a mixture of pigments, chiefly urochrome and a small amount of urobilin. The reaction to test-paper is acid, due chiefly to the presence of the acid phosphate of soda. The origin and destination of the nitrogenous constituents require special

notice, more especially as illustrating the modes of excretion. It is evident that nitrogenous waste matters should be soluble so that they may be carried off in the urine *Urea*, of which about five hundred grains are eliminated daily, is readily soluble in water It is a carb-amide, and is represented by the formula $CO(NH_2)$. It contains the same elements as cyanate of ammonia, but it has not the same molecular structure. Under the influence of various enzymes, it takes up water, and is changed into ammonium carbonate, which gives the ammoniacal odour to decomposing urine. In such urine we always have a precipitate of phosphates of lime, phosphate of magnesia, and the ammoniaco-magnesian, or triple, phosphate, as these are not soluble in an alkaline fluid. As already pointed out, a large proportion if not the whole of the urea is formed in the liver by the splitting up of protein matter that has come from the intestine, and, to be more precise, it is formed from amino-acids. This is sometimes spoken of as the exogenous formation of urea. Along with urea we always find traces of *ammonia*.

One of the substances produced by the decomposition of muscle-protoplasm is a nitrogenous body called *creatine.* By union with the elements of water, it splits into urea and sarcosine, showing a relationship to the former substance, and possibly part of it may ultimately be converted into urea, as it does not appear normally in urine. A closely allied substance, differing from creatine as regards its formula by the loss of the elements of water, is *creatinine,* which always exists in urine. It is in all probability formed, not from the creatine of muscle, as was once supposed, but from the metabolism of protein in the liver, and as it is poisonous it is thrown out in the urine. There is still obscurity on this point. Another nitrogenous waste product in the urine is *uric acid,* of which from seven to ten grains are separated daily. Unlike urea, it is highly insoluble, but being an acid it unites with the alkalies, soda and potash, to form *urates,* which are highly soluble, and in this form it is thrown out. If in excess, or if there is not sufficient base to unite with it, uric acid may appear in various crystalline forms in the urine, and when this habitually occurs, various symptoms of illness may appear which are spoken of as gouty or rheumatic. There can be no doubt that uric acid is derived from the breaking down, not of cell-substance, but from the oxidation of nuclein, one of the chief chemical substances in the nuclei of cells. This shows that even nuclei, on which the activity of cell-life so much depends, are the seat of metabolic changes, and that there are processes of breaking down. It is known that nuclein yields, during certain chemical reactions, a chain of nitrogenous bodies, all more or less closely related, known as the *purine* bases. These are purine, hypoxanthin, xanthin, adenin, guanin, and uric acid. They sometimes appear in the urine and they abound in such tissues as are the seat of active metabolism. Certain foods, such as liver and sweetbread, contain these substances. These bases may thus be formed exogenously from food stuffs or endogenously by the metabolism of tissue. Any increased activity in nuclei, implying tear and wear, is shown by the appearance of these bodies.

We have only recently had a glimpse into the transformations by which members of this series, ending in uric acid, are formed. This is done by the activity of various enzymes found in the tissues. These have been extracted and their chemical activities studied, and there can be little doubt that each of these nucleo-zymases takes its share in the work. Some may bring oxygen into play (oxidases), while others effect specific chemical changes. It would seem that in the liver there also may be an enzyme which breaks up uric acid itself. The ultimate result of these remarkable changes is that substances arising from the breaking up of nuclei are gradually transformed into uric acid, which (as urates) is eliminated in a soluble form. Finally, a substance known as *hippuric acid* is eliminated in small amounts in the urine. It abounds in the urine of herbivora, arising from substances in the food of such animals, and belonging to the benzoic acid series. If benzoic acid is given to a man, it unites with glycine in the liver, with the separation of the elements of water; hippuric acid is thus ormed and appears in the urine. This is a striking example of a synthesis in the living body.

70. Another organ by which excretion is effected is the *skin* This structure not only has a protective function, as it covers the whole surface of the body, but it has also an excretory function. Carbonic acid is to a small extent eliminated. The sweat, consisting of water holding a small amount of salts in solution (chiefly chloride of sodium, and phosphates), is separated by numerous long tubular glands, the *sweat* or *sudoriparous glands*, lined with epithelium. This fluid, at certain temperatures, may at once pass into a state of vapour or gas, thus taking up heat, and cooling the surface, or, as in profuse sweating, it may appear as sensible drops on the surface of the skin. A kind of oily matter is secreted by another set of glands in the skin, the *sebaceous glands*, which sometimes open by ducts on the surface, or into the little pouches from which hairs spring.

Sebaceous matter contains, in addition to water and a very small amount of salts, various fatty acid substances. The sebaceous matter lubricates the surface of the skin. The skin, however, has other important functions. It is not only the organ by which variations of temperature are experienced, but it has to do with the regulation of the temperature of the body. This will be noted in connection with animal heat. It is also the seat of various sensory mechanisms connected with the sense of touch.

71. Matters are also excreted from the body by the *bowel.* These consist of the refuse materials of food which have never really entered the tissues of the body, and which are therefore not true excretions. Along with these there are bodies derived from the bile, such as pigments, etc., and the secretions of the numerous mucous glands found throughout the whole length of the bowel, and more especially in the great bowel. Little is known of the chemical nature of those matters, nor of the exact origin of the large amount of saline

matters, chiefly phosphates, found in the faeces. Finally a large portion of dried faecal matters consists of bacteria, which have already been referred to as existing in enormous numbers in the alimentary canal.

72. There is still another organ which, from one point of view, may be regarded as excretory, namely the *liver*. A portion of the bile is undoubtedly thrown out in the faeces, but others matters are re-absorbed and return to the liver. This organ is the seat of numerous chemical and vital processes that are in a sense hidden. These will be further considered.

73. The bile is an alkaline fluid containing usually a large amount of a mucus-like matter, which gives it a peculiar "ropy" character when poured from one vessel into another. It contains two nitrogenous pigments, *bilirubin* and *biliverdin*. In the bowel bilirubin is robbed of oxygen by reduction processes and becomes the pigment of the faeces, *stercobilin*. Part of the latter may be re-absorbed, and is then eliminated in the urine as *urobilin*, one

of the pigments of the urine. The origin of these pigments is undoubtedly the decomposition of the haemoglobin of effete or worn out red blood corpuscles. Where the haemoglobin is set free and decomposed is doubtful. This probably occurs both in the spleen and in the liver. It is important to note that all the blood that has passed through the spleen goes to the liver. The relation of bilirubin to the blood pigment is undoubted, as haemoglobin is a compound of haematin, containing the all-important iron, and a globulin. If the iron is removed from haematin we have a body called *haematoidin*, or iron-free haematin, produced. This is identical with bilirubin. Thus we see the steps of the process for the elimination of waste pigmentary matters

74. The bile contains the sodium salts of highly complicated acids, known as the bile acids, forming glycocholate and taurocholate of sodium. The first is the more abundant in human bile. Both contain nitrogen; taurocholic acid alone contains sulphur. Each may be split up into (*a*) an

acid, *cholalic acid*, associated with glycin in glycocholic and with taurin in taurocholic acid. Both the origin and the ultimate fate of the bile salts are in obscurity. As they both contain nitrogen, and one contains sulphur, we must look for their origin in protein metabolism, but we know nothing of the steps of the process. In the bile (in human bile glycocholate of soda forms the chief part of the solids) they reach the intestine. We are not aware of any special function fulfilled by them in connection with either intestinal digestion or intestinal absorption. Only a very small amount of the bile salts appears in the faeces. It follows that they must be re-absorbed and carried back to the liver by the portal circulation and again eliminated in the bile. Thus a kind of bile-salt circulation has been imagined, but there is no hint as to any use of this arrangement. Traces of substances may appear in the urine that may have originated from chemical changes in the bile salts. Lastly, small quantities of *cholesterin* or *cholesterol* may be found in bile. It forms the chief constituent of gall-stones, concretions formed in the bile ducts and in the gall bladder The origin of this substance is still imperfectly known, but it is formed from metabolism of tissue. It is present in all cells, and when these are broken down, it is not thrown out as a waste product, but is used up to form new cells. Thus, red blood corpuscles are disintegrated in the liver and cholesterin appears in the bile. It is then re-absorbed, probably with other substances, and is carried to the tissues to form new cells. This is a striking example of physiological economy.

75. By those various processes of excretion waste matters and injurious matters are removed from the blood, as has already been explained. This fluid is therefore maintained in a condition of physiological equilibrium, and this is more remarkable when we consider that it is constantly the seat of exchanges. It is almost momentarily receiving matters on the one hand and giving them up on the other. In a sense, everything removed from the blood must more or less alter its quality. From this point of view the growth and development of the epidermic cells on the

surface of the skin, and which are constantly being shed from the surface in myriads, the growth and development of all epidermic appendages, such as hairs, nails, horn, feathers, etc., remove certain matters from the blood and alter its quality. We may indeed go farther and say that the development and growth of all tissues, as they depend on matters taken from the blood, must alter that fluid. Thus we may understand that the abnormal development of any tissue or organ must have a similar effect, and in some such way the nutrition of one organ must affect that of the others.

CHAPTER X

HIDDEN PROCESSES AND ULTIMATE PHENOMENA OF NUTRITION

76. THERE are not a few processes occurring in the body which are so hidden as not to be at all evident to a superficial examination; and yet they are of the highest importance. Several examples of these may now be referred to. First, we will consider what is usually called the *glycogenic function of the liver.* This organ, the largest gland-like structure in the body, consists of myriads of cells, the hepatic cells, and it is more richly supplied with capillary blood vessels than any other structure in the body. It receives two kinds of blood, red arterial blood from the systemic circulation by the hepatic artery, and blood more like venous blood, often laden with matters derived from the alimentary canal—portal blood—by the portal vein. The blood,

after circulating through the liver, is carried off by a single vein, the hepatic vein, which pours it into the systemic venous circulation. There it mixes with other venous blood, reaches the right side of the heart, passes to the lungs (pulmonary circulation), is sent on to the left side of the heart, and is then propelled by the systemic circulation to all parts of the body. Thus, as already mentioned, the whole of the blood that has circulated through the alimentary canal passes through the liver before it reaches the general venous system. This is the *portal circulation.* In the cells of the liver very active metabolic changes take place, new substances are formed, complex bodies are split up, possibly red corpuscles are decomposed, and as the result of all this, we have bile formed, which, as already seen, passes into the first portion of the small bowel, the duodenum. The formation of bile was at one time regarded as the proper function of the liver. But it is now known that this is not the case. The bile is only a by-product led off from this remarkable manufactory.

77. As already pointed out, the blood with

which the liver is supplied by the portal system contains during the digestive and absorptive processes large amounts of proteid and of carbo-hydrate in the form of grape sugar. What happens to the proteid has already been discussed (p. 66). A portion of it, however, may be decomposed into a nitrogenous and a non-nitrogenous portion. The nitrogenous portion may, by synthesis, assist in the formation of other molecules of proteid or of certain bodies found in the liver, such as the complicated bile acids which, united to soda to form the *bile salts*, appear in the bile (p. 140). In the chemical changes affecting the nitrogenous portion one of the bodies formed is undoubtedly urea (p. 132). This substance often represents an excess of proteid in the diet; at all events a meal rich in proteid is followed by an increased formation of urea. The urea is washed out of the liver by the blood, but as it is quickly removed by the kidneys, it appears in the urine, and the percentage amount in the blood is always small. On the other hand, the non-nitrogenous residue of the proteid may apparently be transformed into a carbo-hydrate, and it may be one of the sources of the distinguishing carbo-hydrate in the liver known as *glycogen.*

78. The chief source of glycogen, however, is undoubtedly grape sugar that has arrived in the portal blood from the alimentary canal. Glycogen is a non-nitrogenous body much resembling starch, indeed it may be regarded as an animal starch. After a period of digestion and absorption, it is found in the form of minute granules in the interior of many hepatic cells. For a time it is stored in these cells, so that the liver is a storehouse of carbo-hydrate. It is interesting to note that in digestion, as we have seen, all carbo-hydrate is transformed into grape sugar, while in the liver we find the process reversed and a kind of starch, glycogen, is again formed from grape sugar. The first transformation is accomplished by various enzymes, while the second is effected by the living hepatic cells, or possibly by an enzyme in the cells While absorption is going on, a certain amount of grape sugar passes through the liver unchanged, and is carried to the muscles, where

it is used up in the chemical processes occurring in that tissue connected with contraction. During the intervals between absorptive periods, and while no carbo-hydrate is derived from the bowel, the muscles still require carbo-hydrate, and this they obtain from the store of glycogen stored in the hepatic cells. How the glycogen is removed from the cells, and again re-transformed into sugar, either in the hepatic cells, or in the colourless corpuscles, or in the muscular tissues themselves, has not yet been clearly explained. Probably again enzyme action is called into play. Another enzyme has been found in the liver, capable of transforming the glycogen into sugar, and various sugar-forming substances have been found in muscle. There appears to be in muscle, especially at an early stage of development, a variety of glycogen, or carbo-hydrate destined for its nutrition. The phenomena that occur in the hepatic cell are unknown. It is possible, as already suggested, that the transformations in protein matter, as well as in carbo-hydrate matter, may be one intricate chemical operation—a series of decompositions succeeded by syntheses—one result of which is the throwing out of useless residues that are found in some of the constituents of the bile. The glycogenic function gives us only a glimpse into the nature of the complex chemical phenomena occurring in a hepatic cell. In the liver also there appears to be a destruction of effete red blood corpuscles with the decomposition of hæmoglobin, and the excretion in the bile of pigments and of cholesterol.

79. In recent years a remarkable discovery has been made with regard to certain organs that were previously a puzzle to physiologists, such organs as the thyroid body or gland found in front of the upper end of the trachea or windpipe; the two suprarenal bodies found immediately above the upper end of each kidney; the pituitary body found at the base of the brain; the spleen, lying on the left side of the stomach; and various organs now known to belong to the lymphatic system, such as the lymphatic glands, the tonsils, and the Peyerian glands found in the small intestine, more especially in its third and lower portion,

the ileum. These organs all agree anatomically in having no duct. Hence, they are sometimes called the *ductless glands.* It is a misnomer to call them glands, as they are not in any sense true glands, and they would be more aptly designated " body " or " bodies." All those organs that belong to the lymphatic system proper contain a peculiar kind of tissue, known as lymphoid tissue (found also in the marrow of bone and below mucous surfaces), consisting of a network of fine fibres, with small masses of protoplasm at the junctions of the fibres, as if the tissue were formed of star-shaped cells, the rays of which unite or anastomose to form a network. These lymphatic bodies are concerned in the development and growth of colourless cells of the blood, but it is probable they have other hidden functions at present unknown.

80. The other bodies above mentioned are now known to form what have been termed *internal secretions,* which have important physiological effects. Thus the *thyroid body* forms a chemical substance, now known as thyroidin, which contains iodine, and which

seems to have the property of destroying mucinoid material, probably absorbed, in a more or less modified condition, from mucous surfaces. At all events atrophy of the thyroid body produces a peculiar disease known as myxoedema, in which the cellular tissues are infiltrated with a mucinoid matter, while there are symptoms of an anaemia (deficiency of red cells of the blood). This condition is much modified or disappears on administering raw thyroid, powdered thyroid, or the thyroidin extracted from the organ of the sheep or similar mammal. As curious nervous symptoms appear after removal of the thyroid it may have other internal functions.

81. The *suprarenal bodies* were at one time thought to have to do with the formation or modification of pigment, and possibly this may be the case, but they are now known to produce a chemical substance termed *adrenalin*, which has a specific action in stimulating non-striated muscular fibre. Thus it stimulates the coats of the arterioles, causing their calibre to be very much diminished, and as the heart still vigorously beats, the

pressure of the blood in the great vessels is much increased, a condition, within limits, favourable to a vigorous circulation. Adrenalin is now used medicinally, as a powerful styptic by which bleedings may be arrested. *This is a striking example of a so-called internal secretion.*

82. Similarly the *pituitary body* appears to exert an influence on the growth and development of bone, and morbid conditions of the organ are apparently related to a curious disease called acromegaly, in which the bones of the face and fingers in particular become enormously developed. This subject, however, is still obscure.

83. Another organ which is the seat of many hidden processes is the *spleen.* It is the largest of the ductless glands. It has a strong fibrous capsule, and passing from the capsule in all directions into the interior of the organ we find septa or partitions of connective tissue and unstriated muscle, dividing the organ into numerous compartments. These are filled with *spleen pulp.* This pulp consists of finer fibres forming a

kind of network, in the meshes of which are numerous granular corpuscles like those found in lymph. There are also numerous red corpuscles and also cell-like bodies enclosing red corpuscles or pigmentary matter. The splenic artery which brings blood to the spleen divides into branches like the twigs of a tree; there are no capillaries; the blood infiltrates the pulp; and from the spaces in which the pulp lies veins originate which, by confluence, form the splenic vein. The blood of the splenic vein, as already mentioned, passes to the liver (p. 140). The spleen has also curious little masses of lymphoid tissue, called *Malpighian corpuscles*, which are closely connected with the branching vessels. The chief function of the spleen is the formation of colourless blood corpuscles, especially by the lymphoid tissue in the Malpighian bodies. The blood of the splenic vein is always rich in white corpuscles. There is little doubt also that disintegration of effete corpuscles occurs in the spleen, and from these chemical substances are formed like those originating in nitrogenous metabolism, such as those of the uric acid series (p. 135).

Curious rhythmical movements of the spleen have been studied, and on a tracing of these movements large waves occur about once in a minute; on these there are smaller waves due to respiratory movements; and on these, again, still smaller waves, corresponding to the beats of the heart. This rhythmic mechanism must assist in the transmission of blood through the organ. It is influenced by special nerves.

84. The *thymus* gland, found in the chest behind the breastbone, is a blood gland of later foetal and early infantile life. Very little is known of its functions.

85. It is suspected that other organs, having definite functions with which we are acquainted, have also hidden functions little understood. In this way the kidneys may have a hidden function; at all events removal of a kidney, or even a portion, has been found to affect the general nutrition of the body. In some similar way the generative organs, ovary and testis, especially during their development, may influence the nutrition of other parts. This is seen to a marked degree

in many animals, more especially in birds in the growth of epidermic appendages, such as the wattles of the male turkey, or the horns of the stag. In man also, when puberty is reached, there are changes in the general nutrition of the female and in the appearance of the beard in the male. Such phenomena have been termed those of *complemental nutrition*, a term of little meaning unless we associate with it the conception that the nutrition of such organs in some way affects the quality of the blood, possibly by an internal secretion, and that this altered quality affects the nutrition of other organs.

86 We have now to approach what is known regarding the processes in the living cell on which the ultimate phenomena of nutrition depend. Each cell, as we have seen, is bathed by lymph which has been furnished by the blood. Under no circumstances does the blood come into direct contact with the living tissues outside the vessels. No doubt the walls of the vessels themselves contain living elements, and we may regard the wall of an ultimate capillary as alive. But, so far

as the outer tissues are concerned, there is always the internal medium, the lymph. This supplies the living cell with matters prepared, as we have seen, by complicated processes, and now fit for assimilation. The lymph also supplies the living matter with oxygen. How they are actually assimilated we do not know; we are now in the most hidden region of life. In the cell we find living protoplasm, and along with it, in many cases, probably in all cases at some period or other of the life of the cell, matters that have been stored up so as to form the elements of secretions, or the substances necessary for the vital activities of the cell.

As examples, takes the granules in a secreting cell which has rested for some time, or the granules in nerve cells, after a period of rest. If we call the protoplasm *a* and the stored matters *b*, we do not know whether *b* has at one time been part of *a*, or whether *a*, by some hidden chemistry, has made *b* outside of its own substance. But there is also intercellular matter, which we may call *c*, and which has been formed by *a*. Such inter-cellular matter we see in the matrix or ground substance of cartilage, the fibrous material of osseous tissue, and the substance of muscular fibre outside the nuclei. The question arises—are *a*, *b* and *c* all alive, or are the phenomena of life to be limited to those occurring in *a*, the protoplasm? There can be little doubt that life must be limited to the protoplasm. We can scarcely imagine the stored matter *b* or the inter-cellular matter *c* to be alive. They do not manifest the general phenomena of living matter, although they may be and are highly complex materials. This brings us then to consider what happens in *a*. Undoubtedly there is evidence that in it there are both anabolic and katabolic processes, processes both of breaking down and of repair, as shown by the appearance in the lymph of chemical substances that could not have been derived from *b* but only from *a*. According to this view, only matter taken up into *a*, assimilated by it, becomes alive, but it is doubtful if even here we can draw a dividing line between what is living and what is dead. We forget that we may here be in a region where there are no sudden jumps but transitional processes. Even when matter has been taken up by the living epithelium of the alimentary canal, it has been altered. Thus protein matters, as we have seen, are split up ultimately to form bodies known as amino-acids; these, in passing through the living epithelial cells, are synthetized into serum albumen or other blood proteins; these again are probably modified in the protoplasm of lymphoid tissue and in lymphatic bodies; and ultimately the protein matter, no longer like the same protein that it was at first, is now, in the lymph, brought near the living matter of the cell. Here we may assume that these prepared proteins are linked on to the living matter by hidden chemical affinities, and thus become incorporated with it. There have been no sudden leaps, but a series of processes; there is no sharp dividing line between what is dead and what is living. So-called dead matter, by these processes, has acquired properties it did not possess before; and so-called living matter has by the process that we call nutrition developed new properties which we say are shown only by matter which is alive. But only living matter can carry out these transitions. They cannot be accomplished by either *b* or *c*—only by *a*.

It is conceivable that it is by purely physical processes that matters are taken up by the living cell, so as to reach the protoplasm. The thin layer of structureless matter lining the wall of a living cell, and indeed, so far, constituting the wall, may act like a membrane used in physical experiments on osmotic action. It is well known that such a membrane may allow certain substances to pass, while it is impermeable to other substances. The matters that can pass through are soluble in the matter forming the membrane, while insoluble substances are rejected. In the living matter, the protoplasm, we have seen that chemical processes occur. But physical chemists know that many chemical processes are reversible, that is to say, in the first stage, from certain bodies (*a*) other bodies (*b*) are formed, and in a second stage, and under different physical conditions, (*b*) may again become (*a*) by the chemical process being reversed. Such phenomena may happen in a cell, and they may account for so-called anabolic and katabolic changes.

CHAPTER XI

THE LIBERATION OF ENERGY

87. We have already seen that energy is liberated by the splitting up of complex into simpler substances. By liberation we mean the setting free of energy as kinetic energy. Thus by the explosion of gunpowder or of gun cotton, the mass is resolved into gases at a high temperature, and the expansion of these gases is used to drive a projectile from a cannon. The energy of the explosive is resolved into heat and motion. This latent energy may be set free by communicating to it the shock of a hair trigger, and the amount of energy of the hair trigger is infinitesimally small compared with that set free by the explosion. The energy of the trigger may be regarded as a liberator of the energy in the explosive. This analogy helps in understanding the phenomena in certain tissues. Thus

in muscular tissue, energy is latent when the muscle is at rest, but when the nervous impulse reaches it by travelling in a nerve the muscle contracts, becomes warmer and does work by motion, in one form or another. The nervous impulse is the liberator,—the muscle substance, along with the chemical phenomena we have considered, liberates energy as heat and motion. In like manner, energy is stored up in all living matter, in the secreting cell, in the tissues of the nervous system, and probably in other living tissues, and it is set free by a nervous impulse. This explains why heat is developed in a secreting gland during its activity, and if we had adequate experimental appliances, we should find evidence of *heat* in all vital activities.

88. Heat is also produced in the body in other ways. The friction of the blood on the walls of the vessels as it is driven along in the circulation is resolved into heat, in other words all the energy of the circulation becomes heat. In like manner the movements of organs causing friction produce heat. But the great sources of heat are the phenomena

that occur in muscle and in secreting glands, The amount of heat produced in other ways is comparatively small. The body may also receive heat by the ingestion of hot food or drink and by conduction and radiation from the surrounding medium. The amount of heat thus produced in a living body is very large, and if it were not lost from the body in in some way, the mean temperature of the body would soon rise to a degree incompatible with life. But the arrangements for the removal of heat are efficient. It is thrown off from the body into the surrounding medium by conduction and radiation if the temperature of the medium is below that of the mean temperature of the body. Heat is lost by, in some circumstances, taking cold food or drink, or by the evacuations. It is also lost by becoming latent in the evaporation of sweat from the surface of the skin, that is to say heat is lost in converting the sweat into vapour. Thus the body is maintained in normal circumstances at a mean temperature in the armpit of 98.40° Fahrenheit.

89. If we estimated all the heat entering the

body and added it to that produced in the body itself, say in twenty-four hours, it would normally be about equal to that given off by the body in the same time. The income and the expenditure would be about equal, and the mean bodily temperature would be fairly constant. If more heat were produced than could be got rid of, as in fever, the mean temperature would rise, whereas if less heat was produced than was given off the mean temperature would fall. It would appear that vital activities can be carried on efficiently only within a narrow range of temperature. Hence the danger to life, in many diseases, if the temperature rises above 104° or 105°. A fall of temperature ten or twelve degrees below normal temperature is not so dangerous. The activity of the skin in producing sweat, and the evaporation of the sweat, is the great regulator. Hence there is danger to life in certain parts of the tropics where there may be an air temperature above 98° F., and where the air, at that temperature, may be saturated with aqueous vapour. Here evaporation from the skin is impossible, heat penetrates from without, and the mean temperature of the body must gradually rise.

90. Energy is also liberated as *motion* by the contractions of the muscles. The muscles may either perform internal work,—as the beating of the heart, the movements of respiration, the movements of the limbs on the trunk, the movements of the involuntary muscles, as of the bladder and bowel,—or external work, as in locomotion or in mechanical labour. All internal movement is ultimately resolved into heat. The external work can also be measured and expressed as heat, and thus the total energy of the body in twenty-four hours liberated by a man doing say eight or ten hours of hard work can be calculated. Further, the energy represented by the complete combustion of a diet sufficient for a man doing this work and producing heat during twenty-four hours can also be calculated. It can be shown that there is a balance struck between income and expenditure, and this balance, in ordinary circumstances, is fairly constant. It becomes interesting to consider man as a transformer of energy with special reference

to the amount of energy he can liberate as mechanical work and the ratio of this amount to the amount of energy appearing as heat. The best results show that about 25 per cent. of the available energy appears as work, with 75 as heat. This compares favourably with many human contrivances. The best steam-engine can only give about 12½ per cent. of the energy produced by complete combustion of the fuel, but gas or petrol engines can do much better—as much as 96-98 per cent. of energy can be transmuted by certain electrical contrivances. The heat of the engine, however, is a real loss of energy, and all engineers strive to reduce it to a minimum, *but the heat of the body is one of the all-important conditions of its mechanism.* The source of error in all such estimations is that food stuffs are never completely oxidised in the body, and further that the methods followed by the engineer in measuring the output of energy are different from those of the physiologist. Still the general statement is fairly correct.

91. In some animals energy is liberated in the form of *electrical energy or light*, as in the electric

fish and the glow-worm and fireflies. Even in the human body there are also electrical phenomena. Every contraction of a muscle, the secretion of a gland, and probably also nutritional changes in the tissues, are associated with electrical phenomena, which may be demonstrated by a sensitive galvanometer and suitable methods. It can be shown that antecedent to every muscular contraction there is generated a change in the electrical condition of the muscle. Whether this electrical state is an expression of the chemical changes in the muscle, on which motion and heat depend, or whether it is an isolated physical phenomenon, it is difficult to say. Even the heart beats are associated with electrical phenomena. Living nerves also show electrical changes similar in kind to those found in muscle. It is significant that the electrical organs of fishes are modifications of muscles or glands. Thus the electrical organs of the *Torpedo occellata* (of the Mediterranean), of the *Gymnotus electricus* or electric eel (of the Orinoco), and of the skates (*Raia*) are all modifications of muscle, while that of the mud-fish of the Nile, *Malopterurus electricus*, is a modification of glands of the skin.

92. Further, it would appear that modern views as to the nature of solutions, in relation to electrical and other actions, must also be applied to the living tissues. Thus salts may act not as salts, but in solution the elements may exist separately as *ions*, related to either the positive or negative poles of a current, or carrying electrical charges, and that physiological activities may vary according as the anion (positive pole ion) or the kation (negative pole ion) comes into play. There are thus in living matter subtile phenomena of which we yet know very little.

CHAPTER XII

THE REGULATING MECHANISM. NERVOUS SYSTEM

93. The nervous system controls and regulates all the organs and even the tissues of the body while, at the same time, all the organs contribute to its upkeep and nutrition. In a sense, too, it binds together the various organs and systems of organs so that they act harmoniously and it confers individuality on the body It is the channel, also, by which influences from the external world act on the central nervous organs through the organs of sense. Finally it is the seat of consciousness and of all mental operations. The nervous system is highly specialized. At the beginning of development it arises from the ectoderm of the embryo and it pursues its own mode of development So necessary is it to the well-being of the body that it is nourished and has its waste products

removed by special arrangements, while it is, as far as possible, protected from injury.

94. Essentially, the nervous mechanism consists of centres, nerves, and nerve-end organs. The *centres* are in great masses constituting the brain and spinal cord, and in smaller masses found scattered here and there, known as ganglia. The *nerves* are found almost everywhere, as whitish cords, varying in calibre from the largest nerves, such as the sciatic in the back of the thigh, down to minute filaments invisible to the naked eye and requiring the use of the microscope for their detection. Each nerve is composed of minute fibres, all of microscopic dimensions, and each showing a central rod or axis, surrounded by a sheath, called the white substance, and this, in turn, usually covered by a thin membrane, the neurilemma. These matters are all of soft consistence and are apparently structureless, but, by special methods, details of structure may be seen. Thus the central axis is sometimes composed of fine fibrils, and the surrounding matter, the white substance, is composed of elongated

flattened nucleated cells. The analogy of a nerve-fibre to a copper wire surrounded by an insulating sheath is striking, the wire for conduction representing the central rod or axis, while the insulating sheath is the white substance. Still it is only an analogy. Nerve fibres vary much in diameter. Many have no white substance; primitive fibres are destitute of it, and it makes its appearance late in development. Nerves consisting of bundles of fibres divide and subdivide into more and more delicate fibres, until, as already pointed out, they are so minute as to be invisible to the naked eye. If we trace the axis of a fibre to its beginning we find that it always originates from or in a nerve cell.

95. Suppose a nerve were laid bare and it were stimulated, say by gentle shocks of electricity, so feeble as barely to be felt by the tip of the tongue, one or more results might follow: (1) a muscle might contract, and then we call the nerve *motor* because it produces motion of a muscle; (2) a gland might begin to secrete, showing the action of a *secretory* nerve; (3) blood vessels might diminish in

calibre as occurs when a *vaso-motor* nerve is acted on; (4) pain might be felt when the nerve is *sensory* and carries impulses to the brain; (5) if it were a nerve of special sense, such as the optic or the auditory nerve, there would be a *sensation* of light or colour, or sound; (6) in an electric fish, the result might be an electric shock from the electric organ These phenomena are often complicated. Sometimes we have a nerve that has only one function, that of causing, say, motion or secretion, but usually a large nerve consists of fibres having different functions. For example, a nerve may contain both motor and sensory fibres, and might serve in part to excite movement, and in part to convey impressions of touch or temperature or pain. When a fibre is stimulated no physical change can be seen with even the highest powers of the microscope. Nerves may also be conveniently classified for physiological purposes into (*a*) *centrifugal*, those conveying impulses from nerve centres outwards, and *centripetal*, or those carrying impulses from the outer parts of the body to nerve centres.

96. A change passes along a fibre when stimulated. This may be termed a *nervous impulse.* We do not know what this change is; no movement of matter can be observed; obscure chemical phenomena have been noted, as shown by the necessity for oxygen and the production of carbonic acid. Electrical charges can be detected which seem, like the nervous impulse, to pass along a nerve, but are not to be confounded with it; and the impulse travels along the fibre with a velocity of only 200 feet per second, incomparably slow, as compared with the velocities of electricity or sound. Recent observations, made with a new form of galvanometer—Einthoven's string galvanometer—a very sensitive instrument, seem to show that the velocity is considerably greater than has been supposed. It would seem also that when the fibre is stimulated at any point the impulse travels in both directions. Nerve-fibres are conductors, but, unlike an electrical conducting arrangement, they are not *only* conductors, because, at the point stimulated, a change is there generated which is then

transmitted, and apparently with accumulating energy. So far as can be observed, all fibres act alike.

97. Nerves, composed of fibres, may be divided, and if rejoined they will re-unite and act as before. This has led to the experiment of dividing two adjacent nerves, (*a*) motor, and (*b*) sensory, and reuniting the ends so that the upper end of *a* is joined to the lower end of *b*, and *vice versa*; they may then unite and functions may be restored. It is evident that if the upper end of *a* was motor and conducted downwards, while the lower end of *b* was sensory and conducted upwards, the nervous impulse in one or the other nerve must now conduct in the reverse direction to what it did before division But if a nerve is only a *sensitive conductor*, why are the results of stimulation so various? It is due to the fact that the *result depends on the apparatus at the end of the nerve.* If the fibres end in muscle, there will be motion; if in a gland, secretion; if in a blood vessel, change of calibre; if in a special part of the brain, sensation or pain. The analogy to

electrical arrangements is helpful, but we must be careful to remember it is only an analogy. Confusion results from introducing words that have a definite meaning to electricians, such as resistance. There is no evidence of any such phenomenon in nerve. If, however, we take the analogy of an electrical current, it might be caused to produce light, heat, motion, or the decomposition of water. All would depend on the arrangements at the end of the wire conducting the current. Finally, as a nerve is a sensitive conductor, irritation at any part of its course will always produce the same effect. We may irritate a nerve close to a muscle or far from it, but the result will be a muscular contraction. We may irritate a nerve near the sentient brain, or far from it, but the resultant sensation will be the same, only, in this case, the origin of the impulse will be referred by the mind to the beginnings of the sensory nerve, say in the skin of the hand. An illustration will assist the reader. Suppose a telegraph message were transmitted from Glasgow to Edinburgh, and that the clerk in the office in

Edinburgh was in the daily habit of receiving such a message; it would not matter to him if one day the message was transmitted to him from a station half way between Edinburgh and Glasgow; he would still believe it came from Glasgow and he would, if necessary, reply to that city.

98. It is convenient, in the next place, to consider the *end-organs*. These are highly specialized organs found at the ends of centrifugal nerves, and at the beginnings of centripetal nerves. The endings of motor fibres in muscular tissue are an example of the first, and the structures in the skin connected with the sense of touch represent the second. End-organs are adapted to the stimulation of certain tissues by the nervous impulse coming from a centre or to the awakening of a nervous impulse by stimuli acting on the end-organ. Thus we have end-organs in muscle at the termination of motor fibres; nerve fibres can be traced into actual contact with secretory cells and blood vessels; and, in electrical organs, into specialized structures constituting the electric tissue

On the other hand, each organ of a special sense has a terminal organ, such as the retina in the eye, the various organs in the skin connected with touch, and the wonderful arrangements in the internal ear suitable for being acted on by the vibrations of sound. There are also end-organs in muscle and in tendons by which nervous impulses are awakened in these structures by movements, and the impulses so generated are carried to nerve centres. We do not know how end-organs act. Those of muscle, for example, may in some way excite the muscle protoplasm so as to cause a kind of physiological explosion ending in the inevitable contraction. We do not know how the nervous impulse acts on a secreting cell. Sensory end-organs, on the other hand, as we shall see in considering the senses, are each adapted to the reception of their specific kind of stimulus. Thus the retina is adapted to light, the structures in the internal ear to sound, the structures in muscle and tendon to pressure, and so on

99. We have next to turn our attention to

the *central organs*, which are by far the most complicated and most difficult to understand. They consist of the brain, the spinal cord or marrow, and ganglia. *Ganglia* are small masses of nerve matter found in many parts of the body, and they abound in many organs, as in the heart and in the mesentery. Such small nodules of nervous matter consist of supporting tissue, nerve cells, and nerve fibres. From one point of view, the spinal marrow and the brain may be regarded as masses of ganglia fused together during countless ages of evolution. All ganglia, be they simple or complex, are known to be composed of certain morphological elements or structural units. These units are supported and protected by a specialized form of tissue, the *neuroglia*, which, however, is not ordinary connective tissue, although that may also enter into the composition of nervous structures. The units are known as *nerve-cells*, or *neurones*. These vary much in general form and size, but they have certain general characteristics. They are composed of protoplasm in which there is a well-defined nucleus, and both in the cytoplasm (protoplasm of the cell) and in the nucleus, there are fine fibres and networks, while chromatin is abundant in the nucleus. In the protoplasm of the nerve cell we find numerous granules. These are more abundant after the cell has rested for a while, and they seem to be used up during the period when the cell is active. The exhausted cell, during the next period of rest, again becomes crowded with granules as it revives. Thus it behaves like a secreting cell. Processes, or as they have been called, *poles*, issue from the cell. These are sometimes few in number, but in many cases each cell may have four, five, or six processes. All of these processes, *except one*, divide and subdivide so as to form smaller and smaller processes, like a branch of a tree dividing until we reach the ultimate twigs. The branch of a tree seen against a winter sky is a picture of the arrangement. The remaining process is the *beginning of the axis of a nerve fibre*, around which the white substance is developed at a later period. The ultimate unit of the nervous system therefore is now designated as a *neurone*, the fine processes produced by some of the poles constitute branchlets or *dendrites*; a mass of dendrites forms a *dendron*, or tree-like structure, and the process that is the origin of a nerve-fibre is the *axon*, or central rod. Next, imagine the branches of two adjacent trees freely intermingling, but not touching each other. This is a picture of the relation of two or more neurones. The dendrites do not form a network, as was once supposed; they do not even touch; there is, as has been aptly said, *contiguity but not continuity* of structure Where dendrites come close together without touching, as if they were almost clasping, we have what is called a *synapsis*. The dendrites may sometimes form a network in close proximity to, or even enveloping, the body of, an adjacent neurone. This network is called an *arborization*. We do not know what phenomena occur at a synapse or arborization. The axon is a process of a neurone, and it may be of great length or it may be short. Thus axons from neurones in the lower part of the spinal cord, for example, may extend unbroken to the foot. It would appear they may divide and subdivide, and as the mass of matter must increase as the fibre passes onwards, the material forming the conducting central part of a nerve-fibre must also increase. This has been well established in the electric fish *Malopterurus*. In this animal the electric organ in each half of the body is set into action by the activity of one gigantic neurone in each half of the spinal cord, each minute portion of the electric organ is supplied by a nerve fibre, and the sum of the diameters of these fibres is many thousand times greater than the diameter of the axon where it issues from the giant neurone.

100. The *central nervous system* is built up largely of masses of neurones, supported by neuroglia. These masses constitute what is called the *grey matter*, found in the centre of the spinal marrow and in and more especially on the surface of the brain. Grey matter is always supplied by a very rich plexus of capillaries formed by the subdivision of arterioles ramifying and subdividing in the mem-

branes covering the brain and cord. A great blood supply always means intense physiological activity. Along with the grey matter, in the central nervous organs, brain and cord, there are strands of nerve fibres constituting the *white matter*. This is not so richly supplied with blood. In both brain and cord there are special arrangements for removing waste products. In a sense the organs lie in lymphatic sacs or bags, and while there are no special lymphatics, each minute vessel is surrounded by a sheath, perivascular so-called, which contains lymph. The grey matter is thus richly nourished, while waste products are quickly got rid of and carried off.

101. Little is known of the activities of a nerve-cell. As already pointed out, granules of matter are used up, but we do not know what is the composition of these granules (Nissl's *granules*). Chemical substances of a protein nature, and especially rich in phosphorus compounds, abound in the protoplasm of a nerve cell. The activity of the protoplasm depends more on an ample supply of oxygen and the removal of waste matters than any other kind

of protoplasm. It is doubtful if the protoplasm of a neurone, say in the brain, can act for longer than a few seconds without oxygen, and the removal of waste matters. Hence there is immediate loss of consciousness if the supply of blood is cut off from the cerebrum, and if the quality of the blood be altered by the presence of even small amounts of poisons the effect is quickly felt. Nervous matter is also extremely sensitive to shocks or variations of pressure. Thus a sudden concussion will often produce unconsciousness. The activities of the nervous system, and especially mental activities, depend on the interplay between grey matter and blood, and the limit of adaptation as regards blood supply, quality of blood, and temperature, is apparently very small. Nearly all the other functions of the body, in a sense, are working towards the end of the adequate nutrition of the grey matter.

102. There are certain definite mechanisms connected with nervous activity that must now be noticed. Sometimes if a sensory nerve is stimulated, there may be no sensation or

pain, but movement of a muscle or a group of muscles, possibly in some distant part of the body. This is known as a *reflex* action. It implies a *sensory* nerve, by which an impulse is carried to a centre, a *centre* in which a change occurs, the nature of which we do not know, and a *motor* nerve carrying an impulse to muscles and causing a contraction. The term reflex, although in general use, is misleading, as it suggests something reflected like a ray of light by a mirror; but we have no better word at present. We know that something occurs in the centre, as time is occupied. Assuming the velocity of the nervous impulse and a given length, both of (*a*) sensory and of (*b*) motor nerve, more time is occupied in a reflex action than the sum of times occupied in *a* and *b*. This increased time is in *c*, the centre. Reflex mechanisms play an important part in the body Many are very complicated, involving several sensory and several motor nerves, and even the centres may be complicated. As an example of a simplex reflex, we may take the movement of winking of the eyelids. Here the sensory nerve may either be the sensory nerve of the skin and of the eyeball (the fifth cranial nerve), or the optic nerve itself through the retina, while the motor nerve is a branch of the seventh cranial nerve, the facial, supplying the muscle that closes the eyelids (*the orbicularis palpebrarum*). The movements of swallowing and the respiratory movements are examples of highly complex reflex actions, involving many nerves and many muscles. We may or may not be conscious of reflex movements, but they cannot be arrested by an effort of the will. Many movements, at first consciously performed, become reflex without consciousness, as in locomotion, playing on an instrument and working a machine. The centres are found in the brain and cord.

103. The nervous mechanisms we have considered cause increased activity. It is probable that even while apparently at rest molecular phenomena are occurring in nerve cells. Thus certain nerve fibres issuing from neurones in the spinal cord pass to the muscles of the limbs and keep these in a state of partial contraction or *tonus*, as it is termed. In this way muscles are not loose but firm and slightly contracted, even while at rest. And when a more powerful nervous impulse reaches them, they are ready to contract efficiently. To use a nautical phrase, the muscles are not on the "slack" but always "taut," and no energy is lost in "gathering them in." But certain nerve fibres have the power, not of causing, but of restraining activity. Such nervous actions are said to be *inhibitory*. A striking mechanism of this kind is seen in connection with the innervation of the heart

104. This organ has numerous little ganglia in its own substance, and possibly these may have to do with its rhythmic contractions, although this is doubtful. Two great pairs of nerves give off branches that can be traced into the heart. These are the vagi, which come from the medulla oblongata, the portion of the spinal cord inside the skull, and the sympathetics, that arise from a chain of ganglia running along each side of the vertebral column. The fibres in these ganglia are derived from the cord by the anterior roots of the spinal nerves. Suppose the heart to be beating rhythmically, stimulation

of the sympathetic in the neck causes it to beat slightly faster, but stimulation of the vagus, also in the neck, causes the heart to beat more slowly; stronger stimulation may stop the heart altogether, and it will then be found that it is arrested with all its cavities dilated, that is to say, the muscle substance is at rest. This action of the vagus is said to be *inhibitory* or restraining, while that of the sympathetic is *accelerating*.

105. Such inhibitory phenomena have been found in connection with many nerve centres. For example the sympathetic is the nerve that acts on the muscular walls of small vessels, keeping them in a state of partial contraction, and thus, as already explained, maintaining a high blood pressure. If this pressure rose too high, the heart would have more work to do in driving the blood onward with increased resistance. The centre (*vaso-motor*), which thus acts through the sympathetic, is in the medulla, and it is assumed that impulses are constantly passing from it to the vessels. This centre, however, may be inhibited by the action of a nerve passing from

the heart upwards. If we stimulate this nerve, called the *depressor*, impulses pass upwards which inhibit the centre in the medulla, throwing it, as it were, out of action, with the result that the arterioles dilate and the blood pressure falls. Other nerves apparently may affect this centre in an opposite way, causing it to act more powerfully, and therefore raising the blood pressure. These are called *pressor*-nerves, in opposition to the depressors. Most sensory nerves act as pressor-nerves. Nerve centres are thus often under the action of impulses having contrary effects, while they are also influenced by the quality of the blood circulating through them. Inhibitory mechanisms play an important part in the nervous machine. Probably the restraining powers of what we term the *will* have a physiological basis of this nature.

106. The *spinal cord* may be regarded as a series of segments combined together to form one mass. Each segment has a pair of spinal nerves, each connected with the central grey matter by two roots. The anterior root consists of motor fibres carrying nervous impulses outwards from neurones in the grey matter. These fibres mostly supply the muscles of the trunk and limbs on the same side. They also pass to blood vessels, and probably to glands, through the ganglia of the sympathetic The posterior roots consist of fibres that convey sensory impulses into the cord. On this root there is a ganglion containing neurones Sensory fibres, coming from the skin, muscles, and other organs, are related to the neurones in the ganglia, and from these neurones new fibres spring, which carry impulses into the cord. The neurones in the ganglia on the posterior roots are the first receiving stations of sensory impulses. Many of such impulses are then conveyed upwards to the brain, and may give rise to sensations of various kinds. Each segment of the cord, however, is connected with a number of segments both above and below it. Many of the sensory fibres of the posterior roots come into relation with neurones in the cord in one or more segments. From these neurones axons arise, which find their way into the anterior roots and thence to the muscles.

Thus we have many reflex mechanisms, which do not involve higher centres. Sensory fibres pass up the back part of the cord to higher and higher centres, calling forth higher reflex mechanisms, but many, as already indicated, ultimately reach the sensory part of the cerebrum, and give rise to *consciousness* or sensations of various kinds. The sensory paths are therefore mainly in the posterior part of the cord, and these pass ultimately to the brain *on the opposite side*, the crossing taking place in the cord and in the medulla. Thus sensory impulses from the right side ultimately reach the left cerebral hemisphere, and *vice versa*. Many sensory impulses also reach the cerebellum, or lower brain. Voluntary motor impulses arise in the cerebrum, pass downwards through the lower parts of the brain, cross to the other side in the bulb or medulla, run down the anterior part of the cord, and, as they pass down, they turn into the grey matter and end by arborizations (like the twigs of a tree) that are close to, but do not touch, the dendrites of large neurones in the grey matter. These give off the axons that become the nerves of the muscles Thus these large neurones in the anterior part of the grey matter of the cord have fibres reaching them from the posterior roots, and are thus the mechanism of reflex acts, but they are also related to the upper cerebral centres so as to be the mechanism for voluntary acts. It is important to notice that the axons of neurones in the higher parts of the nervous system may become related by arborizations to neurones lower down, and the reverse is also true, lower neurones becoming similarly related to higher ones. It may only be an analogy, but the whole mechanism suggests a series of relays such as one might conceive in a very extensive telegraphic system. In a telegraphic relay the current may be caused to work a mechanism a long way off; by this mechanism another current may be started, and so on, until the terminal station is reached.

107. It would appear that in movements, such as those of locomotion, caused by antagonist groups of muscles, such as those that bend the forearm on the arm (flexors) and those that extend the arm (extensors),

we have a kind of double nervous mechanism. Thus, when a nervous impulse causes flexors to contract there is, at the same time, an influence which inhibits or restrains the extensors. The nervous machinery therefore is often very complicated.

108. The part of the cerebro-spinal system within the skull consists of the following structures :—(1) a double chain of large masses of grey and white nervous matter, forming from before backwards; (*a*) the *corpora striata*, (*b*) the *optic thalami*, and (*c*) the *corpora quadrigemina*; (2) still farther back (*a*) the *pons*, (*b*) the bulb or *medulla*; (3) covering the whole of these masses we find the two hemispheres of the *cerebrum*; and (4) on the back of the pons and bulb and below the posterior part of the cerebrum, we find the *cerebellum*. These structures are all connected with each other by strands of white matter formed of nerve fibres, while grey matter is found in masses or nuclei. The fibres carry impulses either upwards or downwards. There are also numerous fibres passing from one lateral half of the brain to

the other side. The grey matter in the pons and bulb gives origin to fibres which run into the great cranial nerves, analogous to, but much modified from, the pairs of spinal nerves. We may shortly indicate the functions of such nerves. Some of the cranial nerves are entirely motor, conveying impulses to the muscles of the face on the opposite side, such as the seventh nerve, that innervates the muscles of expression; others are entirely sensory, such as the optic and the auditory; while a third class are sensori-motor, containing both sensory and motor fibres, such as the fifth, the sensory nerve of the face, but which also contains motor fibres for the muscles of the tongue.

109. The *bulb* or *medulla* contains centres connected with respiration, the action of the heart, and the blood vessels. The latter is the vaso-motor centre already referred to. In the bulb also originate the roots of some of the cranial nerves. Passing through it we also find the motor and sensory paths connecting the brain with the spinal system of nerves. It is important to notice

that both sensory and motor, especially motor, tracts cross in the bulb. This part of the brain is therefore all important to life. If it is destroyed the respiratory, cardiac, and vascular mechanisms quickly cease. It is also the seat of reflexes of a complicated character, such as those of swallowing.

110. The bulb may also be regarded as the most posterior part of the brain, or as the portion of the cord within the skull. It is in a sense one of the most important centres of the body because, as already mentioned, it contains centres for mechanisms absolutely essential to life. A study of its functions also illustrates several fundamental principles. Although not of large dimensions it contains, in addition to fibres passing through it, and conveying impulses upwards and downwards, the following centres: (*a*) respiratory centres; (*b*) cardiac or heart centres; (*c*) vaso-motor centres for the peripheral blood vessels; and (*d*) centres for swallowing. As each centre is double, owing to the bilateral symmetry of the nervous system, there are at

least eight nuclei of grey matter in the medulla, all of which are important. The neurones in this grey matter are all intimately related to each other. The bulb is also richly supplied with capillary blood vessels, and it lies practically in a lymphatic space while perivascular lymphatic channels surround its vessels. Waste matters are thus quickly removed. All the blood vessels in the bulb are of remarkably small diameter, as one would expect. To and from this centre, or rather group of centres, there run numerous nerve fibres connected with the vagi or pneumogastric nerves, and some of the cranial nerves. Fibres also pass into the sympathetic chain of ganglia.

111. As already mentioned, the bulb has to do with the innervation of the heart and of the respiratory mechanism. Both of these movements are rhythmic in their character We feel this in the beat of the heart and in the regular periodic movements of inspiration and of expiration. If these movements depend on the bulb, the question arises as to whether or not the bulb acts automatically. Is there

such a thing as automatic action in the nervous system? One can imagine a nerve centre acting automatically. Suppose that in some way nervous energy is stored up in the centre until there is such a state of tension as to cause a discharge along certain nervous paths. This discharge would lower the tension and there would be an interval during which energy would be again stored until the next discharge, and so on. This would be an automatic mechanism. Research has shown, however, that this is not the way in which the nervous centre works. It is not automatic, but it is influenced, first, by the quality of the blood flowing through it, and it is, in the second place, controlled or regulated by nervous impulses coming by sensory paths from the periphery. Consider this with reference to the respiratory mechanism. Inspiration mainly introduces fresh oxygen into the blood, and both during inspiration and expiration there is the removal of carbonic acid. When the blood contains a certain proportion of oxygen, even although carbonic acid is also present, it is bright red arterial blood; but when it contains more carbonic acid and relatively less oxygen, it is dark purplish-hued venous blood. Again, if we breathe deeply a number of times in succession so as to introduce as much oxygen as possible, we can then "hold the breath," that is to say, we can for a time cease breathing. Divers do this before they make their plunge into the sea. In physiological language, blood containing an excess of oxygen produces a state called *apnoea*, during which respiration is suspended. On the other hand, if the blood contains more than a certain amount of carbonic acid, so as to be highly venous, there is a tendency to make rapid movements of inspiration so as to get rid of the excess of carbonic acid and introduce more oxygen. This happens in *asphyxia*, produced from any cause. These phenomena can be accounted for if we consider the influence of the kind of blood circulating through the respiratory centre. When the blood is rich in oxygen, the centre is not stimulated, but when deficient in oxygen and rich in carbonic acid, the centre is stimulated so as to produce inspiratory movements. Two respiratory centres have been by some assumed to exist in the bulb—an inspiratory and an expiratory centre. Then carbonic acid may be supposed to stimulate the inspiratory, while oxygen might either stimulate the expiratory or produce no effect. There can be no doubt, however we may theoretically explain the facts, that the *quality* of the blood affects the respiratory centres

112. But the centres for respiration are also influenced by nervous impulses coming from the periphery. The lungs are supplied by the vagi or pneumogastric nerves. These contain both sensory fibres for carrying nervous impulses upwards to the bulb, where the vagi originate, and motor fibres which supply the muscles of the larynx and the muscular fibres in the walls of the bronchial tubes. The larynx is highly sensitive through the medium of a sensory nerve, the superior laryngeal branch of the vagus, which leaves the main trunk in the neck and is distributed to the lining membrane of the larynx. Experiment has shown that if the

vagus be divided in the neck then irritation of the upper end of the nerve causes deep inspirations, and that strong stimulation may stop breathing with a kind of spasm at the end of an inspiration. This shows that the impulses coming from the lungs are carried upwards to the respiratory centre in the bulb, and that they more especially stimulate inspiration, possibly by acting on the inspiratory centre. On the other hand, stimulation of the superior laryngeal branch of the vagus causes expirations, and strong stimulation may stop respiration at the close of an expiratory spasm. Impulses therefore coming sometimes from the larynx excite expirations. Now one can imagine the terminal fibres of the vagus in the lungs to be stimulated by venous blood; impulses would then be sent to the inspiratory centre in the bulb. This would be stimulated, with an inspiration as the result. But inspiration is a muscular act involving the diaphragm and the muscles that raise the ribs, while expiration is an act mainly due to an elastic recoil of the lungs and of the walls of the chest. Consequently there is no necessity for calling into play the expiratory centre except occasionally when there is more or less obstruction to the free exit of air from the lungs. This explains the mechanism of coughing, which consists of violent expiratory efforts. But the inspiratory centres may be influenced through other nervous channels. Strong stimulation of almost any sensory nerves will cause inspirations. Slapping the skin with a wet cloth, plunging into cold water, a sudden draught of cold air, pain, will usually cause inspirations. Probably the first breath of a newly-born child is thus excited. Finally, impulses may come to the respiratory centres from the higher centres in the brain. Thus, within narrow limits, we can voluntarily control the breath. When by certain morbid changes in the higher centres, there is unconsciousness, breathing may still go on, but in a curious, fitful way, as if a mechanism regulating the respiratory centres had been interfered with. So that the respiratory centres are maintained in a condition of physiological equilibrium by numerous nervous impulses coming to them by sensory filaments, and also by the quality of the blood flowing through them. They are not automatic.

113. The same is true of the other centres in the bulb. Thus the cardiac centres, acting downwards through the vagi, tend to inhibit or restrain the contractions of the heart, as already explained, while fibres that find their way from the cord into the sympathetic have an accelerating action (p. 187). We may therefore assume the existence in the bulb of inhibitory and accelerating cardiac centres. These again are influenced by peripheral impulses. From the heart impulses may pass to the bulb centres and then to the cerebral centres and from them again downwards to the centres in the bulb. Impulses may also reach the cardiac centres along any sensory nerve, and in this way there may be a degree of inhibition or acceleration, or impulses may come from the seat of conscious emotion in the cerebral centres and terror may cause the heart momentarily to miss its beats.

114. In a similar way the vaso-motor centres in the bulb may be influenced. The action of

this centre is to maintain the arterioles in a certain state of contraction, and this, as already explained, keeps up the blood pressure. But this centre may be inhibited by impulses coming from the heart by the depressor nerve (p. 188), while the centre may be stimulated to greater activity by many sensory nerves which thus act as pressor nerves and raise the blood pressure. Again, the centre may be influenced by impressions coming to it from the brain centres, thus producing the blush of shame or the pallor of fear. It has been found that the vaso-motor centre possesses a kind of inherent rhythm. Thus when all peripheral impulses have been prevented as far as possible from reaching it, the blood pressure still goes through a slow series of variations—that is to say, the muscular walls of the arterioles have a slow rhythmic movement, contracting and expanding in obedience to impulses still coming from the vaso-motor centre. (*Traube-Hering curves of blood pressure*).

115. These nervous mechanisms are pictures of the mode of action of all nerve centres.

There is no automatism, at all events in the nervous centres, but rather a series of changes induced by the quantity and the quality of the blood and by nervous impulses from many quarters Thus the body works as a whole. There is no autocratic centre; the most autocratic, the cerebrum itself, the seat of what we term the will, comes under the same law.

116. The *pons* consists mainly of great transverse bands of fibres passing from one side of the cerebellum to the other. In it there are bundles of fibres passing upwards and downwards and masses of grey matter for some of the roots of cranial nerves. The pons is intimately related to the cerebellum, as the transverse fibres form what are known as the middle peduncles of that organ.

117. Immediately above the pons we find the *crura* or *peduncles* of the brain, containing the great motor and sensory paths. They also contain numerous fibres connecting the cerebellum with the cerebrum. Near the peduncles we find four small bodies, the *corpora quadrigemina*. These consist of layers

of white and grey matter, showing a characteristic structure, and connected with the fibres that come from the retinae of the eyes. They are thus the first recipients of visual impressions transmitted by the fibres of the optic nerves. These nervous impulses may call forth contraction of the pupil, the round aperture in the iris of the eye, or they may excite more complex reflexes, along with the action of the other ganglia in front of them, the optic thalami and corpora striata. These impulses, however, do not give rise to consciousness. A *sensation* excited by impulses coming from the eyes arises only when the impulses are transmitted upwards from the corpora quadrigemina to the visual centre in the cerebrum. By the nervous arrangements, also, the nasal and temporal halves of the retinae are correlated to each other. Thus all the fibres from the temporal side of each retina pass to the *corpus* on the same side, while those from the two nasal halves of the retinae cross and reach the corpus on the other side. Thus the right corpus receives impulses from the temporal side of the right retina and the nasal side of the left, while the left corpus receives fibres from the left temporal and the right nasal side. This secures single vision with two eyes, if the image falls on corresponding parts of the two retinae, as, for example, if it falls on the right temporal and left nasal. But if one image was formed on both temporal or both nasal halves of the retina, there would be double vision, as in squinting.

118. The *optic thalami* are sensory centres, receiving impulses from below, and from them impulses pass upwards to the cerebrum, where they excite consciousness. They (*a*) may act, however, as reflex mechanisms in conjunction with the two masses immediately in front of them, the *corpora striata* (*b*). These are motor centres, receiving impulses from the motor regions of the cortex of the cerebrum (*c*). If *a* and *b* act together, without the influence of *c*, there may be complicated reflex movements, such as occur in the walking of the somnambulist, or the unconscious performance of complicated movements.

119. The highest of all centres is the *cerebrum*, consisting of two hemispheres, show-

ing complicated convolutions. These convolutions constitute an immense web of grey matter showing numerous neurones of a peculiar pyramidal form, arranged more or less in layers. Numerous fibres pass in all directions connecting one part of the cerebral mass with the other. All the structural details indicate co-ordination of function. Thus the convolutions are connected by many *associational* fibres; fibres pass from the anterior to the posterior parts of the cerebrum; and numerous fibres form the great transverse commissure, known as the *corpus callosum*, which connects one hemisphere with the other. Other smaller transverse commissures exist The cerebrum receives nervous impulses from all parts of the body. The sensory tracts in the cord send numerous fibres upwards, and these reach the grey matter of the cerebral convolutions, in the posterior and lateral regions, forming arborizations or networks near motor neurones that lie in layers in the grey matter, more especially in certain convolutions on the lateral aspect of the cerebrum, From these motor neurones fibres (axons) pass downwards through the corpora striata into the peduncles and then downwards in the pons and bulb (where they cross or decussate); they then pass down the anterior part of the cord, until they reach the segment or segments of the cord, in which they end by becoming related to the great motor neurones in the anterior part of the grey matter (see p. 190). Fibres to and from the cerebrum are related to the deep origins of the cranial nerves. Finally, the cerebrum receives numerous fibres from the cerebellum. The physiological mechanism of the cerebrum is still obscure. Portions of the grey matter of the convolutions are concerned in the reception of sensory impressions that are translated into consciousness.

120. Definite districts of grey matter, more especially in the posterior and lateral portions of the cerebrum (temporo-sphenoidal convolutions) receive messages that are translated into sensations of touch, pressure, temperature, vision, and hearing. These areas constitute what are termed *centres for the special senses.* No centre has been identified with taste

The olfactory bulbs and their roots are connected with smell. In the middle region, on each side of the great fissure known as the Sylvian fissure, we find definite *motor centres*, connected with the muscles and limbs and with the muscles of the tongue and face on the opposite side; indeed it is highly probable that every muscle of the body, even the laryngeal muscles associated with the production of voice, has a centre in the cerebrum. When these motor centres are irritated by feeble electric shocks, movements of certain muscles occur *on the opposite side of the body.* Thus, stimulation of one centre, say on the right side of the cerebrum, will cause a movement of one of the muscles of the left hind leg. Again, stimulation of another centre will cause movement of the left fore leg. There are complex centres for the lips, tongue, etc. It must not be supposed, however, that these motor centres are isolated or that they can originate impulses. No doubt they are called into action by nervous impulses of a sensory character coming from other parts of the cerebrum, or from below. Thus they also constitute a reflex mechanism; this appears to be the general plan on which the whole nervous system is constructed.

121. This fact is illustrated by associated movements, such as those of speech or of the hand in penmanship. A spoken word rouses the auditory centre; this transmits an impulse to the motor centres of the speech mechanism; and the word may be audibly repeated. Or the message from the auditory centre may reach the centres for the fingers and arm of the right hand and the word spoken may now be written. Again, the sensory impressions may come from the eye to the visual centre, and it in turn may excite speech or the movements of the fingers and hand. These impulses may be also transmitted to parts of the cerebrum and give rise to *consciousness*. Sometimes in disease one of the links in this physiological chain may be broken. A patient suffering from some form of cerebral disease, when asked the question, "What is your name?" may be unable to answer, not because he does not hear (he is not deaf), but because he cannot utter the words "John Smith" in response,

as the route of the message from the auditory centre to the speech centre has been interrupted. If the physician writes the words, "Is not your name John Smith?" and puts the paper before the patient's eyes, there is the response: "Yes, certainly." Here the message from the visual centre reaches the speech centre, and the patient can utter his name. Frequently also, a patient in certain cerebral diseases may be perfectly conscious of the name of a particular thing that he wants, say a pencil, but he has forgotten the word or uses a wrong one, to his own annoyance. All this may be represented by diagrams, but we must never forget that diagrams only represent men's notions and that the real mechanism may be something very different. The functions of the anterior lobes of the cerebral hemispheres are unknown. Some have supposed that in them we have the mechanism for volition and the impulses that follow it.

122. The *cerebellum* is a regulating mechanism. It may have other functions, but it undoubtedly co-ordinates movements. By co-ordination we mean that the time and

extent and order of a given group of muscular contractions must be regulated to obtain a required result. Thus in writing, many muscles of the arm, fore-arm, and fingers act. Again, in walking, complicated groups of muscles must combine. It seems that in all such mechanisms sensory impulses, or rather impulses from the periphery, of which we may or may not be conscious, start the mechanism. Thus, in walking, impulses may come from the skin of the feet and from the muscles and tendons of the limb or from the eyes. If these impulses reach the cerebrum, we may be conscious of them. Without these impulses even voluntary motion is irregular and inefficient. But many may find their way to the back part of the cord and from it to the cerebellum by what are called the inferior peduncles of that body, which connect it with the cord. The structure of the grey matter of the cerebellum is extremely complicated, and although many details are known to histologists, we can form no conception of its mechanism. But the grey matter shows the usual plan of neurones of various forms, in layers. Round these neurones fibres that come from below form arborizations. From these, fibres proceed that find their way to the cerebral hemisphere on the opposite side and probably end in the motor centres. The function of the cerebellum seems to be to arrange these sensory impulses and to transmit them to the special motor centre in the cortex of the cerebrum, so as to bring about the co-ordination that is necessary for the required movement. Probably they do this by setting into action motor centres for the movements of special muscles. There is a faint analogy in the card of a Jacquard loom, which so arranges the threads as to enable the other mechanisms to weave the desired pattern. Finally, the cerebellum receives impulses from the retina and from the internal ear, and more especially from the semi-circular canals of that organ. Such impressions from these sense organs assist in the co-ordination of movement, and in the maintenance of equilibrium.

123. It cannot be too strongly emphasized that our knowledge of the physiological

mechanism of the brain is still very imperfect. When we examine under the microscope sections that have been prepared by modern methods, we are bewildered while we admire, and there is often the involuntary exclamation, " How does it all work ? "

CHAPTER XIII

RELATION TO THE OUTER AND INNER WORLDS BY THE SENSES

124. When we reflect on the physiological nature of the senses, we find that the mind becomes cognizant of two worlds from which apparently come streams of feeling. There is in the first place the inner world of our own body in which there are physiological operations constantly going on, such as have been indicated in the previous pages. Of some of these operations we are more or less conscious, while many others, and probably by far the greater number, never rise to the level of consciousness even although nervous impulses from many organs and tissues may reach the higher centres. But we have what may be termed *internal senses*, such as hunger and thirst, satiety, the feeling of easy and comfortable respiration, as when we breathe fresh

air, or have a feeling of the enjoyment of life, such as one has in a state of health while in the open air and in fine weather. As a rule, we pay little attention to these internal senses, which seem to be on the very threshhold of feeling, but we are more or less conscious of them when they rise to a certain intensity. Of many organs we are unconscious, except when the nervous impulses coming from them cause sensations that rise to the level of pain. No doubt the nervous centres are almost constantly receiving nervous impulses which, although they may not rise into the sphere of consciousness, yet fill up, as it were, the interstices of our conscious life and give it completeness. There do not appear to be any special mechanisms for these internal senses. The ordinary sensory or centripetal nerves serve the purpose.

125. But we become cognizant of the outer world by the five *external senses* of vision, hearing, touch, taste, and smell, and we learn about our position and movements in the outer world by nervous impulses concerned in what is called the muscular sense, and in the

sense of equilibrium, and of the position of the head in space. These external senses have always a special mechanism, namely (*a*) an *end organ* adapted for the reception of a specific kind of stimulus; (*b*) a nerve of special sense; and (*c*) an internal receptive organ in the brain, which may act without consciousness in reflexes, or with conscious perception in the cerebrum. As an example take the sense of vision. The normal stimulus is light, the end organ is the retina, the nerve is the optic nerve, the recipient centre is in the first instance the *corpora quadrigemina*, or optic lobes (as they are termed, for example, in birds), and the centre of sensations of light and colour are in the cerebrum, more especially in a special area of grey matter.

126. The senses may be classified thus: (*a*) Those in which the stimulus is movement or pressures, namely—touch, hearing, the muscular sense, and the sense of equilibrium; and (*b*) those in which the stimulus is more of a molecular character, implying chemical action, namely—vision, taste, and smell. In the outer world, according to the conceptions

of modern physics, matter is in a constant state of movement, and we also assume the movements of the ether as the cause of the phenomena of heat, light, and electricity. Such movements impinge on the body of an animal of the simplest type, and by a slow process of evolution through countless ages sense organs and a nervous system have been produced. Thus a pigmented spot has slowly become an organ of vision, and a few specialized hairs have been developed into a recipient organ for variations of pressure, a rudimentary organ of touch or of hearing. As we ascend the scale of animal life, the sense organs become more and more complicated until we find them as in man and in the higher animals.

Each sense organ, as already pointed out, is adapted to its specific kind of stimulus. Thus the retina is attuned to receive the vibrations of light, and in the skin and in the internal ear we have structures adapted for receiving variations of pressure. These end organs are composed, putting the matter in a general way, of (*a*) modified epithelial cells to protect and support; (*b*) a highly specialized form of nervous epithelium, which, in its turn, is continued into neurones, and these neurones ultimately, with probably intermediary neurones, end in neurones in the cerebrum. This is well seen in the retina, where the specialized receptive epithelium forms the remarkable layer of rods and cones (Jacob's membrane); the rods and cones and other structures of the retina are supported by modified epithelium, forming structures called the Müllerian fibres; the layers of granules in the retina and the layer of large multipolar nerve cells constitute the neurones. From these latter arise the fibres of the optic nerve, which, as already pointed out, carry impulses to the corpora quadrigemina, and thence to he cerebrum.

127. The nerve of special sense is normally stimulated by the end organ, but it may be stimulated in other ways, as by pressure or electric shock. Thus pressure on the eyeball will give rise to dazzling impressions of light (phosgenes). But the law is that in whatever way the fibres of the nerve of special sense is stimulated, the sensation is always of the

same kind. Thus a luminous sensation always follows stimulation of the optic nerve. When it is divided by the surgeon, in removal of an eyeball, if the patient is conscious, there is no pain but the consciousness of a flash of light. The same applies to all the other senses. This law has been called the law of the specific energy of the nerves of special sense, but it does not imply that the nerve is anything else than a conductor. The effect is due, as has already been explained, to the arrangements at the cerebral end of the nerve, by which the messages are always translated into sensations of the same kind.

128. Each sense organ works within certain limits. Thus a stimulus may be so feeble as not to produce an effect. This, as regards intensity, is the *threshold of sensation.* The end-organ is adapted to respond, say to vibrations, within a certain range. Thus, if we look at a spectrum the eye does not recognize light or colour below the lower limit of the red, but we know that there are vibrations in existence that give rise to heat below the red end. The skin may be affected by these low vibrations,

but not the retina. As we pass upwards, either by increasing the intensity or, as in viewing a spectrum, by increasing the number of vibrations, sensation continues, and it may vary in intensity, or in quality, or in both.

129. The relation between the strength of the stimulus applied to an organ of sense and the intensity of the sensation has been investigated. It is found that the intensity of the sensation increases with an increase in the strength of the stimulus, but in a peculiar way. It is not in direct proportion. For example, doubling or trebling the strength of the stimulus does not double or treble the intensity of the sensation, but the latter increases by smaller and smaller increments until no difference in the intensity of the sensation can be observed. Thus, in a very intense light the additional light of a candle may not be perceived. Refinements of this law have been studied, but the general principle is as above stated. It is evident that there is thus a protective action against injury from excessive stimulation.

130. With regard to vibrations, a sensation

arises when they reach a certain number, and it changes as they increase. This, as already pointed out, is well seen in a spectrum. Proceeding from the low red upwards we pass through the various colours, red, orange, yellow, green, blue, indigo and violet. The range is an octave, that is to say, the number of vibrations producing violet are about double the number required for red. With the sense of hearing, the first tone audible as a musical tone is produced by about thirty-three vibrations per second, while the highest audible tone corresponds to a little over thirty thousand per second. Thus the ear has in most individuals a range of about eleven octaves. Beyond the highest audible sound, there are however many vibrations which make no impression on the human ear, just as there are numerous vibrations beyond the upper limit of the violet of the spectrum, known to physicists, such as the Röntgen rays. These have no effect on the human retina, and yet their existence has been proved by special methods of research. It is possible, even probable, that some animals may hear sounds that are inaudible to man. Our knowledge, therefore, of the external world is limited by our senses, and there may be many phenomena for which we have no powers of perception. For example, we have no organ for the perception of changes in the electrical condition of surrounding matter, and were we supplied with such an organ a new world would be opened up.

131. The *delicacy* of the sense organs is remarkable. Thus we may detect a pressure on the skin of ·002 gram. We can detect the eighth of a degree centigrade when the temperature of the skin is 18° C. The shortening of a muscle may be detected so small as ·004 of a millimetre (1-6,000th of an inch). The ear can detect vibrations of sound caused by movements of molecules of the air of ·0004 mm. (the 1-600,000th of an inch, or 1-10th of the wave length of green light; while the retina is even more sensitive;—the *energy* of the feeblest light that can be distinguished at a certain distance, say 100 yards, is of the same order of magnitude as

that of the feeblest tone that can be heard by the ear at the same distance; one part of sulphate of quinine can be detected in 1,000,000 of water; the odour of one part of bromine, and even much less of iodoform may be detected in 1,000,000 of air. Possibly the senses of some animals are even more delicate.

132. Each organ of sense has *accessory apparatus* suitable to it. Thus the eyeball is a camera for the purpose of forming, in accordance with the laws of dioptrics, an image on the retina. Vibrations of sound are conveyed to the internal ear by a complicated conducting mechanism of a drumhead, a chain of bones, and reach a delicate organ in the cochlea, known as the organ of Corti. By hair-like processes in the semi-circular canals of the inner ear, acted on by pressures of fluid in the canals, varying according to the position of the head, we appreciate the position of the head in space, and we regulate the movements of the body accordingly. In the tongue and nose there are special epithelial structures, such as the taste bodies and the olfactory epithelium acted on by odoriferous particles. In the skin there are plexuses of fine nerve fibres, running even among the cells of the epidermis, which receive delicate pressures, as in touch. These pressures are also detected by nerve fibres connected with specialized structures formed mainly of epidermic cells, such as touch bodies, tactile corpuscles, and Paccinian bodies. No special terminal organs for temperature have been discovered in the skin, but there are points in the skin sensitive to heat, others to cold, and both distinguishable from those devoted to pressure. It would seem there are also pain spots. There appear to be even different systems of sensibility in the skin. If a sensory nerve to an area of skin is divided, sensibility may return if the ends unite. The sensations that return first have been termed *protopathic*, and depend on heat, cold, and pain spots. But another order of sensations return later, and seem to depend on tactile sensations and a finer sense of sensibility to pain. This kind of sensibility has been called *epicritic*. It follows, then, that when we bring the finger flat against a surface we stimulate a complicated mechanism giving rise to different kinds of sensations In recent years it has been more and more clearly shown that in all the terminal organs of the senses there is differentiation to a degree at one time unsuspected.

133. It is important also to observe that there seems to be no correspondence between the physical nature of the stimulus and the sensation. They are absolutely unlike. We have acquired knowledge of the various stimuli, say light or sound, by observation, experiment, hypothesis and theory, but there is no similarity between certain wave lengths of the ether and a sensation of violet, nor between the varying pressure of a wave in the air and the sensation of a musical tone. The sound of an orchestra may be represented mathematically by a curve, and physically by variations in air pressures, but the psychical effect is quite a different thing. We pass at this point from the region of the physical and physiological (both may ultimately be the same) into the still more occult region of the psychical.

CHAPTER XIV

THE VOICE

134. THE human voice is produced by the vibrations of the margins of two ligaments in the larynx called the vocal cords. Voice should be distinguished from speech. Many of the lower animals have voice, but none have the faculty of speech in the same sense as we find it in man. There may be speech without voice as in whispering, while in singing a musical scale we have voice without speech.

135. The apparatus for the production of voice consists of (*a*) a wind chest, the thorax, by means of which a blast of air may be forced from the lungs through the windpipe or trachea to the larynx; (*b*) a sound box, the larynx, containing the vocal cords; and (*c*) the throat, mouth, and nasal, and other passages that modify the sound produced in the larynx. Voice is almost invariably produced

during expiration, but sounds may also be produced by inspiratory efforts. The larynx is formed of cartilages connected by ligaments and more or less capable of being moved on each other by muscles, the muscles of the larynx. The chief cartilages are the *thyroid* or shield forming the prominence known as Adam's apple. Immediately below it is the *cricoid* or ring cartilage, shaped somewhat like a signet ring, with the signet directed to the back. On the signet there rest two small cartilages, the *arytenoids*. These are pyramidal in shape, the bases of the two pyramids resting on the signet of the cricoid while the apices are directed upwards. The true *vocal cords* are two membranes or ligaments stretched from the base of each arytenoid forwards to the thyroid. They are formed of connective tissue fibres, with which are intermingled many fibres of elastic tissue. Running in the larynx from before backwards they leave a narrow chink between their free edges called the *glottis*. During calm inspiration the glottis is widely opened, but on the approach of an expiration the free margins of the cords come closer together and the glottis becomes much narrower. If voice is now to be produced, as when a note is sung, the margins touch and the glottis is entirely closed for an instant. The pressure of the air below the cords is increased by the expiratory effort, and there is a puff of air sent out between the margins of the cords. This relieves the pressure and instantly again the glottis is closed by the elasticity of the cords. Again the pressure rises and there is another puff and so on, and the margins of the cords thus move with each puff; in other words, they vibrate. So that the organ of voice is on the principle of the siren, an acoustical instrument by which musical tones are produced by the fusion of individual puffs of air.

136. The vocal cords can be tightened or relaxed, and their free margins can be separated or approximated by the action of special muscles. Thus, in singing a scale, beginning with the low note, the cords are gradually tightened by two muscles, the *crico-thyroids*, passing from the sides of the signet of the cricord upwards and forwards to the thyroid.

These muscles, when they contract, put the vocal cords on the stretch, and the stretch increases as the pitch of the note rises. If we remember that the true vocal cords pass forward from the arytenoids to the thyroid, and if we suppose that each arytenoid is capable of rotating round a vertical axis passing from the apex of the pyramid to its base, we can understand how the glottis is opened and closed. Two small muscles, the *posterior crico-arytenoids*, pass from the signet of the cricoid to the outer angles of the base of the arytenoids, and when they contract they so rotate the arytenoids as to carry outwards the cords and thus they enlarge the aperture of the glottis. Their antagonists are a pair of small muscles, the *lateral crico-arytenoids*, which pass backwards from the sides of the cricoid to the outer angles of the arytenoids. When these contract they pull the angle forwards and inwards, and thus approximate the cords. By these simple mechanisms the position and tension of the cords is controlled. The amplitude of movement of each muscle is only a very small fraction of an inch, and yet a soprano vocalist can produce a trill with the greatest distinctness.

137. When we listen to musical tones emitted by the human voice we notice variations of pitch, loudness or intensity, and quality. *Pitch* depends on the number of vibrations executed by the cords in a given time, or, more correctly, on the duration of each vibration. Thus in singing a note, say the middle C of the piano, the cords vibrate about 256 times per second. Each vibration therefore lasts the 1-256 of a second. The greater the number of vibrations in a given time the higher the pitch. The range of the human voice is about three octaves—from fa♭ (87 vibrations per second), to sol ♮ (768). In men the vocal cords are more elongated than in women in the ratio of 3 : 2, so that the male voice is of lower pitch. At the age of puberty, the larynx grows rapidly and the voice of the boy "breaks" in consequence of the lengthening of the cords, and it generally falls about an octave in pitch. The highest pitch reached by the human voice is recorded of Lucrezia Agujari, who was heard

by Mozart to sing c in alt, three octaves above middle c (2,048 vibrations), while the lowest is that of Gaspard Forster, who gave a note nearly three octaves below the middle c (42 vibrations). Musical sounds begin with about 32 vibrations per second. These two voices, therefore, had a range of about six octaves, but the usual range between the lowest bass and the highest soprano of ordinary voices is three octaves. The human ear passes in range from 32 to 33,768 vibrations per second, or about eleven octaves, and it is interesting to notice that the range of the human voice occupies about the middle of that vast range. It is said that some have been able to hear tones produced by 40,000 vibrations per second. The tone of the 32-foot organ pipe is produced by about 32 vibrations per second, while the highest tone of the organ, that of the piccolo stop, is produced by about 4,000 vibrations per second. With reference to these figures it is interesting to compare the range of the human voice.

138. Loudness or *intensity* depends on the amplitude of the vibrations of the cords—the

greater the amplitude, or extent of movement, the louder the tone. This will be largely determined, not so much by the force of the current of air from the lungs as by the degree of elasticity of the cords.

189. The quality or timbre of the voice depends on the same laws as determine the quality of musical instruments. The tone produced by the vibrations of the cords is a compound tone depending on a fundamental tone which gives the pitch, with which are combined many partials or overtones, which, as regards the number of their vibrations, are simple multiples of the frequency of the fundamental. Thus, if the fundamental tone is produced by, say, 100 vibrations per second, then the partials are in the order of 1, 2, 3, etc.; that is, the first partial corresponds to 200 vibrations per second, the second to 300, and so on. The cavities above the cords, such as the space immediately above the cords and below the so-called false cords, the cavity of the pharynx, nasal passages, sinuses in the bones of the face, and the mouth, all act as resonance chambers. These develop,

by resonance, a selection of the overtones, and thus give quality to the voice. A very small change in the capacity of these chambers will alter the quality.

140. Speech is the expression of ideas by means of the voice or by the breath (without voice), as in whispering. Speech sounds are produced by the articulating mechanism. Certain open sounds, more or less modified, give the vowels, which are musical tones. So-called consonants are produced in many ways, but these cannot be here discussed. The simplest view to take of them is that they are breaks of, or interferences with, the current of air which, if the mouth were open, and the articulating mechanism were at rest, would produce vowel tones. Physiologically all *words* are made up of certain sounds that may be called *phones*. Each phone may have its own pitch, intensity, and quality; and by their blending a word is produced. Each phone on a gramophone record is composed of curves that vary as to number (pitch), amplitude (loudness) and form (quality), consequently when the vibratory needle

again runs over these curves, the sound must be reproduced. Nature knows nothing of letters and syllables; words are either simple phones or combinations of phones, and each phone is formed of vibrations. This is nature's longhand method of recording speech: written or printed letters and syllables are a species of shorthand invented by man.

CHAPTER XV

DEATH

141. DURING the earlier years of life and up to the period of adolescence, the body increases in size and weight. The processes of growth are in excess of those of waste. After adolescence, the body may remain for many years without much variation in bulk and weight; but even before middle life signs of decay and degeneration are noticeable, especially in certain organs. Grey hairs appear, the teeth decay, there may be a diminution in the elasticity of parts and in the power of the muscles, and there may be slow changes in some of the internal organs that are still compatible with ordinary health. In advanced life these changes become more apparent. Some have supposed that such changes may be due to the action of poisonous substances, formed mainly in the alimentary canal, and even the

phagocytic action of the colourless cells of the blood has been invoked, but there is no clear evidence in support of these views. In old age there is a gradual process of degeneration more or less of all the tissues—the nervous tissues suffer least and last. It is not easy to understand why there should be this tendency to degeneration, and conceivably, in perfect hygienic circumstances, and with an absolutely clean pedigree, such degeneration might not occur. Early death should only be caused by accident. In an ideal physiological life, death should come late as a result of gradually increasing weakness without pain or suffering, and it should be a process as normal as going to sleep. In most instances, however, degenerative changes do not affect all the organs alike. Some, such as the heart, or lungs, or kidneys, probably on account of an error in the mode of life, or a want of adaptability to the environment, may undergo changes that unfit them for their work. This disturbs the physiological balance and there may be suffering ending in death. When this occurs, the mechanism of the heart or of breathing, or of the nervous system, may break down, and death of the body as a whole takes place. The organs, or rather, the tissues in the organs, the cells, the living matter, die more slowly, and at last these too cease to live The organic matter of the body then, under the influence of micro-organisms in the air or the soil, breaks down by processes of putrefaction, and, in course of time, it is decomposed into simpler and simpler organic substances until the ultimate elements are reached. Thus organic matter becomes again inorganic.

142. The causes of longevity are not understood; nor, as already mentioned, is it evident why the degenerative changes above referred to should come on. Each species of animal, at all events among the higher animals, seems to be so constructed as to have a longevity peculiar to the species. Attempts have been made to connect this in some way with the period of utero-gestation, but little reliance can be placed on such speculations. It is clear, however, that longevity is largely a matter of heredity, if accidents

of all kinds are avoided. The contraction of a pneumonia or of a fever in early life may be regarded as an accident which has cut short the normal duration of life.

CHAPTER XVI

PHILOSOPHICAL QUESTIONS AND THE TREND OF PHYSIOLOGY

143. In the brief survey we have given of physiological processes, questions of a philosophical nature cannot have failed to occur to the mind. There is one always keenly debated, namely, the existence of a vital force or energy, as distinguished from the physical forces with which we are acquainted. It does not serve any practical purpose either to deny or to affirm the existence of such a force. As a matter of fact, we are met everywhere with phenomena which cannot be explained by our present knowledge of physical and chemical science. Numerous instances of such phenomena have been pointed out, and it is surely scientific and philosophical to recognize the limits of our knowledge. With the progress of science we may, and indeed

will, get further into the molecular arena, and be able to explain some of those phenomena, which at present are so obscure. We need not proclaim what we do not know, and assert that all of these phenomena are in reality physical, because this is simply begging the question. There are phenomena, however, which we may feel assured can never be so explained. Those of a mental kind can never be thus accounted for, and no metaphysical subtleties, either from a materialistic or an idealistic standpoint, will ever satisfy the mind. How are we to give a physiological explanation of human personality?

144. Progress in physiology can only be made by a resolute investigation of all the vital, physical, and chemical phenomena that occur in living matter and in living beings. This must be done by the methods followed by physiologists, with all the help they can receive from the rapid accumulation of knowledge. At one time anatomical, at other times histological, considerations govern the science. The older anatomists were content to display the organs and to infer their functions. The cell theory

and the genesis of tissues (not a hundred years old) at one time seemed to be the key to an explanation of vital phenomena. Then came a time, not so long ago, when physical methods of investigation were in vogue, and it was thought that many phenomena were merely physical, requiring for their interpretation measurement, weighing, and graphic registration. At the present time, considerations of chemical phenomena are prevalent in the minds of physiologists. The structure of the complex proteins and other bodies is being investigated; syntheses of many organic substances have been accomplished; even elementary protein-like bodies have been formed, and the formation of complicated proteins is within sight. Chemical phenomena in the great processes of respiration, nutrition, and digestion are being thoroughly investigated. The agency of ferments is now recognized as all-important not only in digestion but in nutrition. Osmotic phenomena in living matter have received recently much attention, and some of the visions of advanced physicists as to the constitution of matter have been applied tentatively to the explanation of physiological processes. The result is remarkable. On all hands it is admitted that the phenomena in living matter are much more complex than they were at one time thought to be, and everywhere we are brought face to face with vital conditions which modify the physical phenomena, and which, at present, refuse to be explained. One may be sure that a century hence advanced mathematicians, chemists and physicists (the physiologists of their day) will still be working at the problems of physiology.

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GLOSSARY

Abiogenesis (Greek, *a*, privative; *bios*, life; *genesis*, production).—Spontaneous generation.

Accelerator nerves (Latin, *accelero*, to hasten).—Nerves which, when stimulated, quicken the rate of the heart's action.

Adrenals.—The supra-renal capsules.

Adsorption (Latin *ad*, to, *sorbere*, to suck).—The attraction of gelatin, etc., for certain substances; not solution.

Afferent (Latin *affere*, to convey to). Conveying towards,

Afterbirth.—The placenta.

Agglutination (Latin, *agglutinare*, to cement to).—The gathering together into small masses of bacteria.

Anaesthesia (Greek, *a*, privative; *aisthesis*, perception).—Loss of sensation.

Anion.—An electro-negative body that passes to the positive pole during passage of a current.

Anode (Greek, *ana*, upwards; *odos*, a way).—The positive pole of a battery.

Argon (Greek, *argos*, inactive), a recently discovered element.

Assimilation (Latin, *assimilare*, to make like).—Conversion of foodstuffs into living matter.

Axilla.—The armpit.

Axis cylinder.—The central filament in a nerve fibre.

Bacillus (Latin, *bacillum*, a little rod).—Bacilli are micro-organisms.

Bacteria (Greek, *bacterion*, a rod).—Unicellular micro-organisms having no chlorophyll.

Basement Membrane.—A delicate membrane on mucous and serous surfaces, bearing epithelium.

Blastoderm (Greek, *blastano*, germinate; *derma*, skin) — A layer of cells formed by repeated division of the primitive cells.

Brownian movement.—Rapid motion of minute microscopical particles, first described by R. Brown, botanist.

Brunner's Glands.—Small racemose (grape-like) glands found in the duodenum.

Calorimeter.—An apparatus for measuring the heat of combustion.

Calorie.—Thermal unit.

Cartilage.—Gristle.

Casein.—A proteid, forming chief constituent of cheese. Formed from *caseinogen*, by action of acids or rennin.

Cathode, or *Katode.*—Negative pole of a battery.

Cation, or *Kation* (Greek, *katon*, that which goes down).—An electro-positive body that passes to the negative pole during the passage of a current.

Centrosome.—A minute body found within a cell.

Chemiotaxis (Greek, *chemia*, chemistry; *taxis*, order).—A property of attraction drawing micro-organisms or their products to the white corpuscles of the blood.

Chondrin.—A proteid found in cartilage, etc.

Chromatin (Greek, *chroma*, colour).—Colourable matter found in the nuclei of cells.

Chyle (Greek, *chylos*, juice).—A milk-like fluid absorbed by the lacteal vessels in the villi of the small intestine.

Chyme (Greek, *chymos*, juice).—Semi-digested matter that passes from the stomach into the duodenum.

Coagulation (Latin, *con*, *agere*, to drive together).—The formation of a blood clot.

Colloids (Greek, *kolla*, glue or jelly).—Non-crystallizable matter that does not pass through an animal membrane in ordinary circumstances.

Corpus, *corpora.*—Bodies, such as *corpora quadrigemina*, four twin-like bodies.

Crystalloids.—Substances that in dialysis pass through animal membranes.

Cutis vera.—The true skin.

Cytoblastema (Greek, *kutos*, a cell; *blastema*, growth).—Cell protoplasm. *Cytoplasm*, protoplasmic matter of a cell.

Defensive bodies.—Substances in the blood that tend to destroy micro-organisms. (*Germicidal*, germ-destroying.)

Deglutition.—Act of swallowing.

Deliquescent.—Melting away by absorption of water.

Derma.—The skin.

Dialysis (Greek, *dialusis*, a loosening).—Separation of substances by means of an animal membrane.

Diaphragm.—Midriff, a membrano-muscular partition between thorax and abdomen.

Dissociation.—Splitting up of compounds without chemical change.

Duodenum (Latin, *duodeni*, twelve).—The first portion of the small intestine.

Ectoderm, Endoderm (Greek, *ektos*, outward; *endon*, inward).—Two layers of the early embryo. Ectoderm is sometimes termed the *epiblast*, and the endoderm, the *hypoblast*.

Elastic tissue.—Yellow fibrous tissue, found in certain ligaments.

Emulsion (Latin, *emulgere*, to milk out).—A special kind of mixture of various substances (see text).

Endosmose (Greek, *endon*, within; *osmosis*, impulsion).—The passing of a fluid through an animal membrane from a rarer into a denser fluid.

Enzymes.—Chemical substances secreted by living cells or by micro-organisms which act catalytically. Sometimes termed *ferments.*

Epidermis (Greek, *epi*, upon; *derma*, the skin).—The superficial layer of the skin, covering the *dermis*, or *cutis vera*, the true skin.

Epiglottis (Greek, *epi*, upon; *glottis*, glottis).—A fibro-cartilage in front of the glottis to protect the opening into the larynx.

Epithelium (Greek, *epithemi*, to place upon).—A layer or layers of cells on a basement membrane.

Erythrodextrin and *achroodextrin* are dextrins formed from starch by the action of saliva. The first passes into sugar.

Excretion (Latin, *excernere*, to separate from).

Fallopian Tubes.—Ducts passing from the ovary to the uterus.

Fecundation (Latin, *fecundare*, to make fruitful).—The blending of the male and female elements.

Fermentation (Latin, *fervere*, to boil).—Changes in certain matters caused by enzymes or micro-organisms.

Fibrin (Latin, *fibra*, a fibre).—The fibrous element in blood clot.

Fibrinogen (*fibrin* and, Greek, *gennao*, to produce).—The substance in blood from which fibrin is formed. *Fibrinoplastin*, a globulin in blood.

Ganglion (Greek, *ganglion*, a tumour).—A nodule of nervous matter, forming a nerve centre. In it are found nerve-fibres, nerve cells, and supporting tissue.

Gelatin (Latin, *gelu*, frost).—A proteid found in white fibrous and other tissue.

Glycogen (Greek, *glucus*, sweet; *gennao*, to produce).—Animal starch, formed chiefly in the liver.

Haem-, *Haema-*, *Haemato.*—Terms applied to substances derived from blood, such as *Haemalin*, *Haematoidin*.

Haemoglobin.—The colouring matter of the blood.

Haemolysins.—Substances that dissolve red blood cells.

Haematoblasts.—Small bodies in blood, or blood plates.

Histology (Greek, *histos*, a web; *logos*, an account).—The structure of the tissues.

Hormones (Greek, *hormao*, to arouse).—Chemical substances formed in epithelium which excite the secretion of glands.

Hyperaesthesia (Greek, *huper*, above; *aisthesis*, sensation).—Excessive sensibility.

Hypertrophy (Greek, *huper*, in excess; *trophe*, nutrition).—Excess of nutrition.

Imbibition (Latin, *imbibere*, to drink in).—The passage of fluid into dead or living tissues.

Inhibition (Latin, *inhibeo*, to restrain).—Arrest of function of a nerve centre.

Inosite (Greek, *is*, *inos*, muscle).—A kind of sugar found in muscle.

Ions.—The dissociation of molecules into elements or ions, a name given to the elements of a liquid set free by the passage through it of an electric current (*electrolysis*). Ions set free at the anode are *anions* ; those at the katode, *kations*.

Irritability (Latin, *irritare*, to provoke).—The property of living matter by which it is affected by a stimulus.

Jejunum (Latin, *jejunus*, hungry).—Upper two-fifths of small intestine.

Karyokinesis (Greek, *karuon*, nucleus ; *kineo*, to move).—The changes that occur in a nucleus in connection with cell division.

Keratin (Greek, *keras*, horn).—A substance found in hairs, nails, and other epidermic tissues.

Laevulose (Latin, *laevus*, left).—One of the substances formed from cane sugar by the enzyme invertase. The other substance is *dextrose*.

Lysis (Greek, *lusis*, solution).—Occurs in many words, such as *ana-lysis*, *para-lysis*, etc.

Macula germinative.—The germinal spot in the ovum.

Malpighian corpuscles.—Small bodies in the cortex of the kidney consisting of a plexus of capillaries, forming a ball, which is surrounded by the beginning of a uriniferous tubule (the *capsule*). *Malpighian glomeruli*, in the spleen.

Mes (Greek, middle); mes-enteric (Greek, *enteron*).—Glands : small lymphatic glands found in the mesentery ; the membrane which connects the small intestine with the posterior wall of the abdomen (a reflection of the peritoneum).

Morphology (Greek, *morphe*, form; *logos*, an account).—The science that investigates the laws of form and arrangement of parts of the bodies of plants and animals.

Myosin (Greek, *mus*, muscle).—A globulin found in muscle.

Myxoedema (Greek, *muxa*, mucus; *oedema*, a swelling).—A disease in which the thyroid body is atrophied and the connective tissues of the body are infiltrated with a mucus-like matter.

Neuron.—A nerve cell. See text.

Nuclein.—A complicated chemical substance containing phosphorus, found in nuclei.

Nucleus.—A kernel, a body found in cells.

Oesophagus (Greek, *oisophagos*, *oio*, *oiso*, to carry; *phago*, to eat).—The carrier of food, the gullet.

Ontogenesis (Greek, *onta*, things; *genesis*, creation).—The history of the development of the individual.

Pepsin (Greek, *pepio*, to digest).—The enzyme of the gastric juice.

Periosteum (Greek, *periosteos*, around the bones).—The connective tissue covering of the bones.

Pharynx (Greek, *pharungx*, the throat).—The musculo-membranous bag or cavity leading into the gullet.

Placenta.—The afterbirth.

Protein (Greek, *proteno*, to be in the first place).—A substance containing carbon, hydrogen, oxygen, and nitrogen. Ex.: Albumen (white) of egg.

Proteolysis.—The decomposition of proteins.

Protoplasm (Greek, *protos*, first; *plasma*, something formed or moulded).—See text.

Ptyalin (Greek, *ptualon*, saliva).—The enzyme of saliva.

Pylorus (Greek, *pule*, a gate; *ora*, care).—A gate-keeper. The passage leading from the stomach into the duodenum.

Racemose (Latin, *racemus*, bunch of grapes).—A special form of gland with branching ducts and *acini* or pouches, at the termination of the smallest ducts.

Rectum (Latin, *rectus*, straight).—The last part of the bowel terminating at the anus.

Rennin.—The enzyme found in the fourth stomach of ruminants, and in the gastric juice of young mammals.

Rods and cones.—Structures in the external layer of the retina.

Rods of Corti.—Specialized epithelium in the *scala intermedia* of the cochlea.

Schizomycetes (Greek, *schizo*, to split; *mukes*, *mukatos*, a mushroom).—Split fungi multiplying by fission.

Secretin.—A substance in the duodenum which, by absorption into the blood, stimulates the pancreas to secrete.

Sero-therapy.—The injection of specially prepared blood serum in the treatment of various diseases.

Skatol (Greek, *skas*, *skatos*, dung).—A substance in faeces arising from decomposition of proteids.

Spermatoblast (Greek, *sperma*, semen; *blastano*, to germinate).—Cells that form spermatozoa.

Spermatozoa (Greek, *sperma*, semen; *zoon*, an animal).

Thymus (Greek, *thumos*, an onion).—A blood gland of early life found behind the breast bone.

Thyro (Greek, *thureos*, a shield).—Applied to thyroid cartilage of larynx, and the *thyroid* body.

Trophoblast (Greek, *tropheo*, to nourish; *blastos*, a germ).—A portion of the epiblastic layers of the embryo that has to do with the formation of the placenta.

Urea (Greek, *uron*, uron).—A crystalline substance found in the urine. *Uric acid*. See text.

Vaso-motor.—Term applied to nerves that govern the smaller arterioles.

HISTORICAL NOTES

GREAT PHYSIOLOGISTS

1500—Achillini, 1461-1512. Release of anatomy from the influence of Galen. Practice of dissection.
1530—Vesalius, 1514-1564. Anatomy of heart and vessels.
1540—Falloposis, 1528-1562. Colombus, died 1559. Circulation valves.
1550—Eustachius, 1520-1574. Vessels, etc., Anatomist.
Servetus, 1509-1553. *Discovery of pulmonary circulation.*
1560—Fabricius al aquapendente, 1537-1619. Vessels.
1580—Caesalpinus, 1519-1603. Anatomist. Forerunner of Harvey.
1610—William Harvey, 1578-1657. *Circulation of the blood. De motu cordis et sanguinis,* published 1628.
1620—Asselli, about 1622. *Discovery of the lacteals.*
1640—Borelli, 1608-1679. Animal motion. The heart.
1650—Pecquet, about 1621. Discovery of thoracic duct.
Boyle, 1627-1691. Laws of gases.
1660—Malpighi, 1628-1694. *Discovery of capillaries.*
1670—Leeuwenhoek. *Microscopical investigations.*
Hooke, 1635-1702. Theory of respiration.
Mayow, 1645-1679. *Theory of respiration.*
1680—Ruysch, 1638-1731. Art of injecting vessels.
1700—Boerhaave, 1668-1738. General physiology.
1710—Stephen Hales, 1677-1761. *Hydraulics of the circulation.*
Morgagni, 1682-1771. Beginning of pathology.
1740—Haller, 1708-1777. Theory of muscular irritability.

1760—John Hunter, 1728-1793. Action of vessels, etc.
Spallanzani, 1729-1799. *Digestive process, respiration, generation.*
Galvani, 1737-1798. Animal electricity.
Hewson, 1719-1774. Functions of blood glands.
1770—Volta, 1745-1826. Electricity.
Lamarck, 1744-1829. Theory of development.
1780—Gall, 1758-1828. Dissection of brain.
1790—Humphry Davy, about 1799. Gases from blood.
1800—Thomas Young, 1773-1820. *Measurement of time, theory of colour, hydraulics of circulation.*
Charles Bell, 1774-1842. Functions of nerves.
1810—Majendie, 1783-1855. Theory of absorption.
1820—Beaumont, about 1824. Gastric digestion in man.
Gemelin, 1788-1853. Animal chemistry.
E. H. Weber, 1795-1878. Circulation, muscular action, senses.
Marshall Hall, 1790-1857. Reflex actions.
Flourens, 1794-1867. Central nervous system.
Poiseuille, 1799-1869. Circulation.
1830—Johann Müller, 1801-1855. General physiology. Great handbook. Foundation of modern German school of physiologists.
Schleiden, 1804-1872. *Cell theory.*
Mattencei, 1811-1869. Electro-physiology.
Magnus, about 1836. *Analysis of gases of blood.*
1840—Claude Bernard, 1813-1878. *Vaso-motor* nerves, *glycogenic function*, etc.
John Goodsir, 1814-1867. Secretion, etc.
Fechner, 1801-1887 Psychophysical actions.
Darwin, 1809-1882. "Origin of Species," 1859.
Andrew Buchanan, 1798-1882. Coagulation of blood.
1850—Ludwig, 1816-1895. Hydraulics of circulation.
Hermann Helmholtz, 1812-1894. Muscle—rate of nerve impulse, hearing, vision, *application of physical methods of research.*
Donders, 1818-1890. Vision.

Du Bois Reymond, 1818-1896. Electro-physiology.
Lister, 1827-1912. Blood-coagulation, micro-organisms, *aseptic methods in surgery.*

More recent physiologists, chiefly British, whose writings are readily available :

1. Wooldridge, Halliburton, Hammarston, Fischer (*syntheses of proteid-like bodies*).
2. Electro-physiology.—Hermann, Kronecker, Burdon-Sanderson, Waller, Gotch.
3. Respiration.—Edward Smith, Haldane.
4. Glands and Secretion.—Langley, Starling, Bayliss, Schäfer (*internal secretions*).
5. Nerves.—Langley, Gotch, Sherrington.
6. Nerve Centres.—Hitsig, Fritsch, Ferrier Waldeyer (neuron theory), Golgi, Ramon y Cajal, Sherrington.
7. Heart.—Gaskell, Einthoven ; Pulse—Mackenzie.

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