The Elements
of . . . .
Animal Physiology

W. A. OSBORNE, M.B., D.Sc.

With the Author's
Compliments

The Elements

— OF —

Animal Physiology

— BY —

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Melbourne

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PREFACE.

In this book an attempt has been made to give an elementary account of physiology from the standpoint of the mammal and with special reference to man and the domestic animals. It is hoped that it may function as a text-book intermediate between the primer and the special manual of human or veterinary physiology, and therefore be of use to students of medicine, veterinary science, and agriculture. As the technical terms employed are all defined, and as no presumption is made that the reader has studied chemistry or physics, the book, it is also hoped, may be read with profit by others who may not be entering upon a definite course of professional study.

The writer is naturally under many obligations to the authors of various treatises on physiology. He would, however, make special mention of Hagemann's *Anatomie und Physiologie der Haus-Saügetiere* and Munk's *Lehrbuch der Physiologie*. In the chapter on nutrition, many valuable data have been taken from *The Feeding of Animals*, by Mr. W. H. Jordan, and in the chapter on reproduction, the writings of Professor J. Arthur Thomson, and of Mr. Walter Heape, have been specially utilised.

In the appendix a number of biochemical data are given for the sake of those who have some chemical knowledge.

The separate chapters of this book appeared serially in the Journal of the Department of Agriculture of Victoria between August, 1906, and March, 1909. The writer would here beg to express his indebtedness to the Hon. George Swinburne, M.L.A., the Hon. Alfred Downward, M.L.A., and the Hon. G, Graham M.L,A., Ministers of Agriculture, for their courtesy and for the facilities they gave in the matter of publishing and to Dr. Cherry, Director of Agriculture, and Mr. A. T. Sharp, assistant editor of the Journal of Agriculture, for their goodwill and help.

University of Melbourne, March, 1909.

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Errata

Page 26, heading—*For* Hornome *read* Hormone.

Page 76.— *For* $\frac{\text{length of alimentary canal}}{\text{length of animal}}$

Read $\frac{\text{length of animal}}{\text{length of alimentary canal}}$

Page 124, line 37.—*For* Thalumus *read* Thalamus.

Page 143, line 15.—*For* delute *read* dilute.

Page 144, line 1.—*For* reduce *read* reduces.

Page 147, line 15.—*For* form *read* forms.

Page 148, line 27.—*For* N_2 *read* $2N_2$

Page 148, line 31.—*For* $3N_2$ *read* N_2

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THE ELEMENTS

— OF —

ANIMAL PHYSIOLOGY

CHAPTER I.

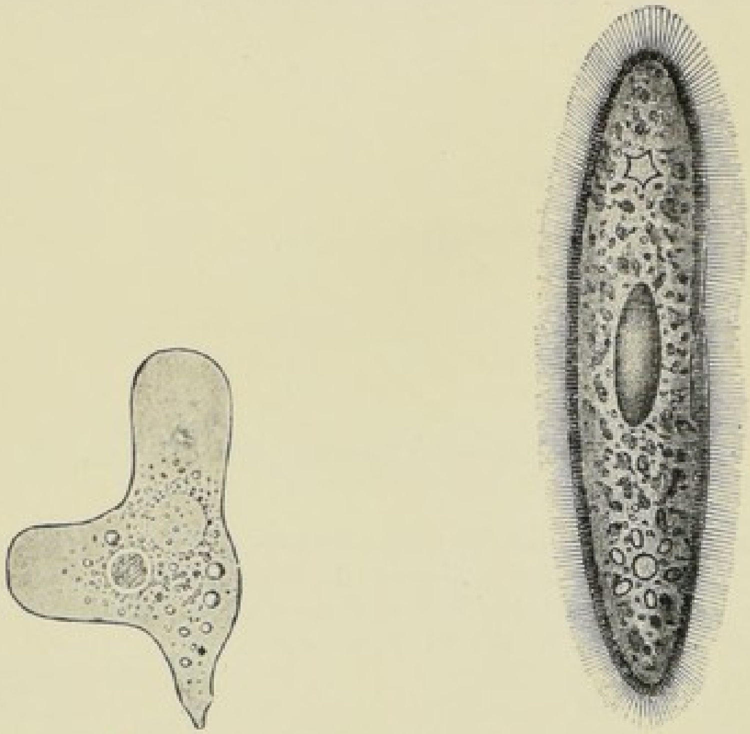
The Essentials of Life.

The best way to understand the working of a complex piece of machinery is to examine the earliest and simplest types. If we know, for instance, the principles on which Stephenson's *Rocket* was constructed we are in a fair way to understand the working of a modern locomotive. The same may be said of living things. The animals we designate by the term *mammalia* are the most complex and the most perfect of all living things, at least on this planet, and, therefore, before we can hope to understand what is known of the workings of their bodies we must first of all study the earlier and simpler types of life. Now, a snake is lower in the scale of life than a horse, but it is still high compared with the fish; whilst far below the fish we must place the worm. In this way we can go down the long ladder of living things until we come to a point where animals and vegetables meet, and below which there is no other form of life possible. This lowest, simplest, and oldest type of living thing is the SINGLE CELL.

There are very many varieties of such lowly developed creatures. For instance, the micro-organisms which enter our bodies and cause disease; some of these are plants, for example, the bacteria of consumption, lock-jaw, and diphtheria; some are animals, such as the germ of malarial fever. Yeast belongs to this lowest class of life, and is looked on as a plant; a teaspoonful of yeast is really a vast horde of individuals, each composed of a single cell; also the microscopic creatures which may be seen to sparkle in the sea at night when the water is disturbed—these latter belong to the animal kingdom. But all these living things at the bottom of the ladder have this in common that each individual is composed of a single cell.

Structure of the Cell.

A cell consists of a body called the NUCLEUS, enclosed in a layer of substance called the PROTOPLASM. In most, if not all, cases, the protoplasm is lined on the outside by a thin covering called the CELL WALL. The nucleus is always a small body, and it so happens that the layer of protoplasm covering the nucleus can never be very much deeper than the width of the nucleus; hence it is that most living cells can only be seen under the microscope, and some of them only when high powers of magnification are employed; a very few may be seen by the naked eye, but they are never more than a few millimetres* in length. In contrast to this limitation in size, we find that the shapes which living cells display are unlimited. But in all cases there is a nucleus, and beyond the nucleus there is a protoplasm, and, we may further add, beyond the protoplasm is a watery fluid, either fresh water, sea water, or some watery solution.†



A B

Fig. 1.—(*a*) *Amœba* (magnified). An animalcule found in stagnant water. The dark body is the *nucleus*, and beside it is a pale *pulsating vacuole*, which, by altering its shape, keeps the protoplasm in movement. (*b*) *Paramæcium* (magnified). An animalcule found in water in which hay has been soaked. It has a well-marked *nucleus*, and two *pulsating vacuoles*. All round are tiny protoplasmic feet (*cilia*), which, by rapid movement, can propel the cell in any direction. (After Verworn.)

Protoplasm is neither solid nor fluid, as we usually understand by these terms; it rather resembles unboiled white of egg in consistency. When viewed under the microscope it presents a dotted appearance, as if delicate strands of firmer material were running in all directions through it, forming a meshwork. Here and there in the protoplasm are minute particles of substance which the cell is about to push outside, or is storing up for use as food. The nucleus is probably a little firmer than the protoplasm, but its structure is far more complex. In fact, a nucleus is an

* A millimetre = $\frac{1}{25}$th inch approximately.
† The term BIOPLASM will be used to denote both protoplasm and nuclear substance.

intricate mechanism rather than a simple substance, and it is in and around the nucleus that the greatest activities of the cell are manifest. Of the supreme importance of the nucleus many experiments give evidence. It has, for instance, been found possible in some of the larger single-celled creatures to tear off a portion of the protoplasm, and thus divide the cell into two parts, one with, and one without the nucleus. The unnucleated protoplasm continues to show some signs of life for a short time, but it has no power of repair or growth, and very soon dies. This is prettily shown with the *Polystomella*, a cell with a calcareous wall, which can be broken in the manner described. In the portion retaining the nucleus the

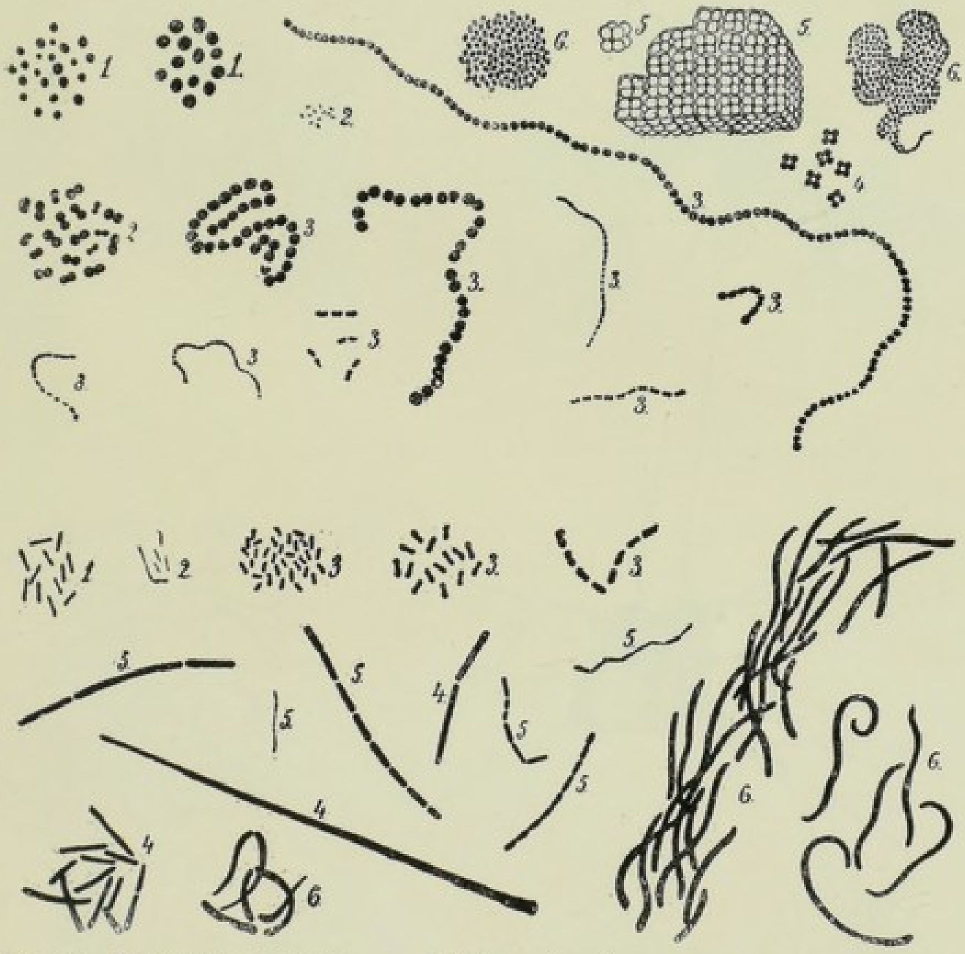


Fig. 2.—Illustrations of the manifold variety in size and form of different bacteria. (After P. Baumgarten.)

wound is speedily closed up with a new shell, and the cell's activities continue unabated; the unnucleated portion, however, goes rapidly to pieces, and is eaten up by other micro-organisms. We may lay it down then, as an all-important law in physiology, that, IF A CELL BE DIVIDED, THAT PORTION WHICH RETAINS THE NUCLEUS MAY LIVE, THAT PORTION WHICH IS CUT OFF FROM THE NUCLEUS MUST DIE.

Fundamental Characters of Life.

There are some characters common to all living things, both high and low, which may now be considered briefly:—

1. RENEWAL AND REPAIR.—It is essential to life that the different structures employed should be constantly renewed, not in large portions at a time, but each part in a gradual manner. We are familiar

with the mending and renewal of the parts of a machine, such as a bicycle; at one time a new tyre, at another a new spoke is added, until, as sometimes happens, no single part of the original structure is present. But if, instead of these parts being inserted complete and at separate times, the renewal was constantly being effected—if in every moment of the bicycle's existence each spoke and tube and screw was taking a minute amount of fresh material into itself, and throwing out a minute amount of old material, if the paint and rubber were not only replaced as soon as rubbed off, but were constantly being renewed in the same slow and continuous manner—

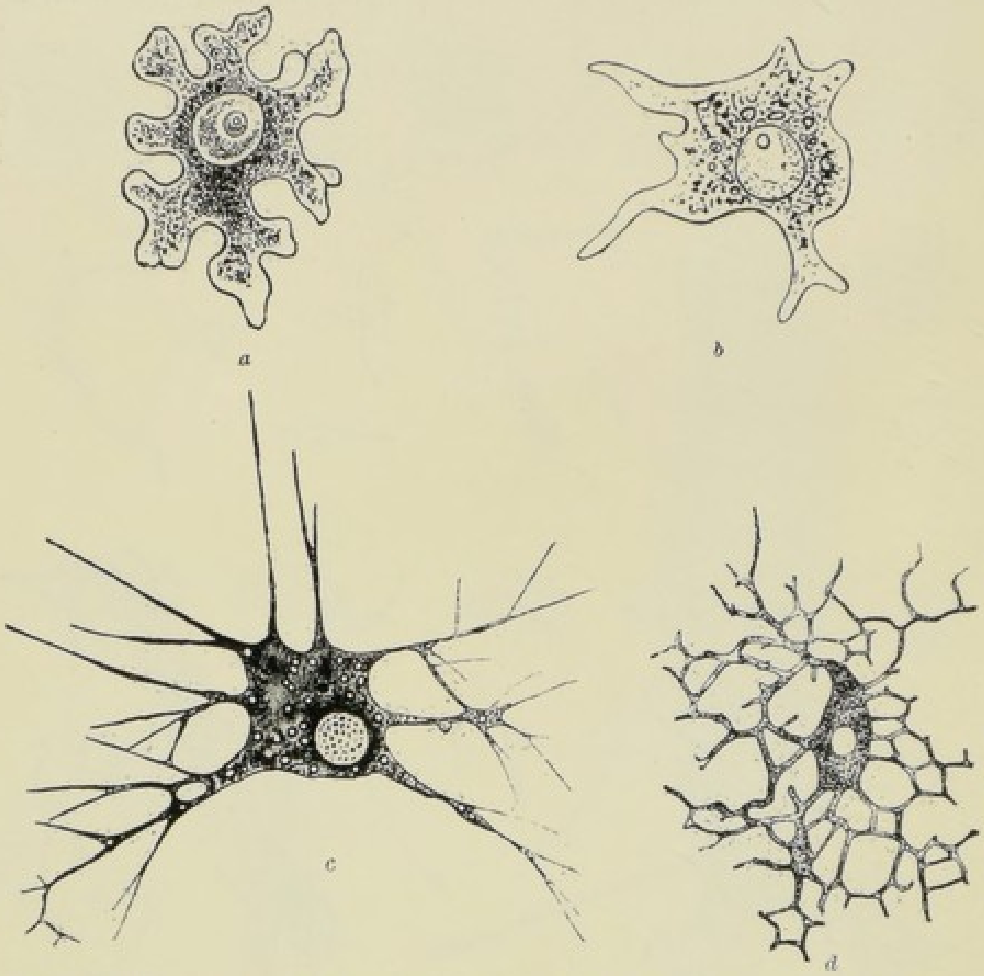


Fig. 3.—Showing four different types of motile cells. (*a*) Egg cell of a calcareous sponge; (*b*) blood cell of a crab; (*c*) a fresh water animalcule; (*d*) pigment cell from the tail of a tadpole. (After Verworn.)

we should have a better model of a living thing. Certain larger portions of the organism which have been lost by accident may be replaced. We have seen that the *Polystomella* can mend a gap in its shell; a lizard can grow a new tail, and, in the same way, a mammal can grow a new piece of skin after a cut or a burn. But there is a limit to this power of replacing a large portion of substance. We, for instance, if we lose a finger or an eye, cannot grow a new one, much less an arm or a leg. In fact, the higher an animal is developed the less power it has to make good such losses; one reason being that in the higher animals the parts lost are far more complex than analogous portions of lower animals, so that, unfortunately, repair is out of the question.

Now, to enable the animal to keep this renewal and repair in progress, it is necessary that it should take up fresh material, in the shape of FOOD, and to eject old material in the form of EXCRETIONS.

2. ABSORPTION OF ENERGY AND PERFORMANCE OF WORK.—Most animals move their bodies about, chiefly to obtain food or to escape from danger, and in doing so perform work. Even those single-

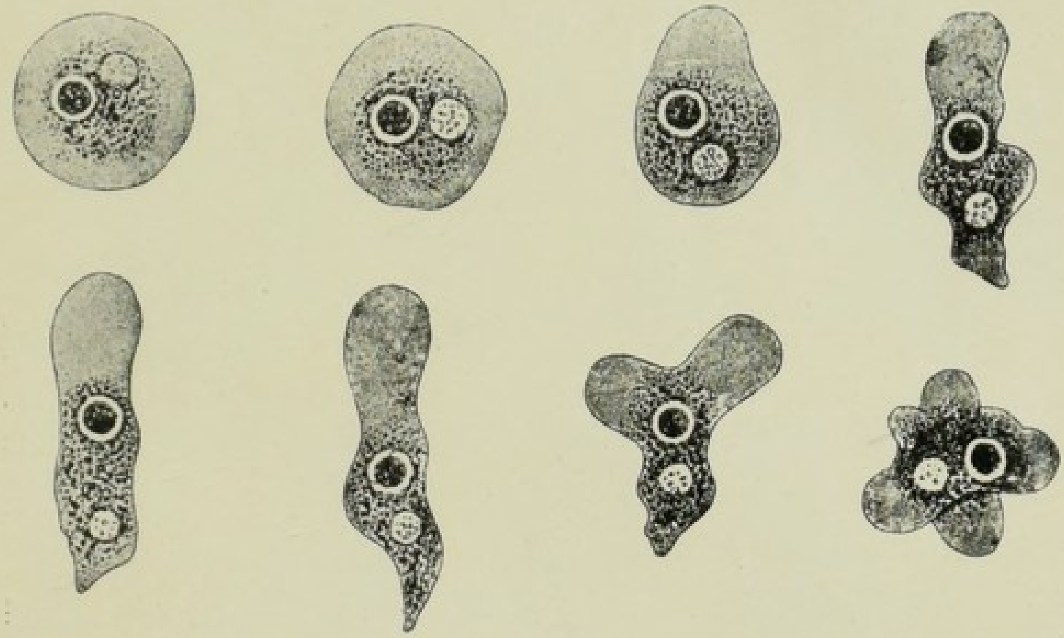


Fig 4.—*Amœba* in eight successive stages of movement. (After Verworn.)

celled organisms, which show no movement, such as yeast cells, perform work, for in these, as in all cells, the protoplasm is in continuous movement; other activities, too, such as the discarding of waste material and taking up of fresh, and the various chemical reaction, to be described later, are continually at work.

Now, no work can be done unless energy is expended, and we have to consider whence the energy comes. We shall find that all the energy utilized by living things, both plant and animal, is derived from THE BREAKING DOWN OF COMPLEX UNSTABLE COMPOUNDS INTO SIMPLER AND

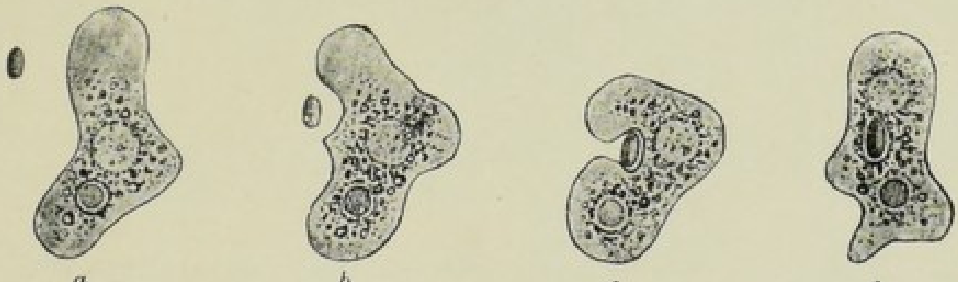


Fig. 5.—*Amœba* approaching and capturing a particle of food, in four successive stages. (After Verworn.)

MORE STABLE SUBSTANCES. For instance, the yeast plant takes up sugar, and splits it into alcohol and carbon dioxide. Now, experiment shows that the heat produced by burning a definite weight of sugar is greater than the heat produced by burning that weight of alcohol, which would be derived from the sugar. The carbon dioxide cannot be burnt, it is at the bottom of the energy ladder. Now, this difference of heat between burning sugar and burning alcohol represents so much energy which the yeast plant can have at its disposal. Another instance is the lactic acid bacillus.

which changes sugar into lactic acid. Here, too, if we burn some sugar and the corresponding weight of lactic acid, we find that the latter gives off less heat, and this difference means so much energy which the bacillus can use. But the quickest and one of the simplest methods of breaking down unstable bodies into stable, and so liberating energy is OXIDATION. A bee or other insect will eat sugar, but it is not content with a break-down into alcohol or lactic acid, it oxidizes the sugar completely into water

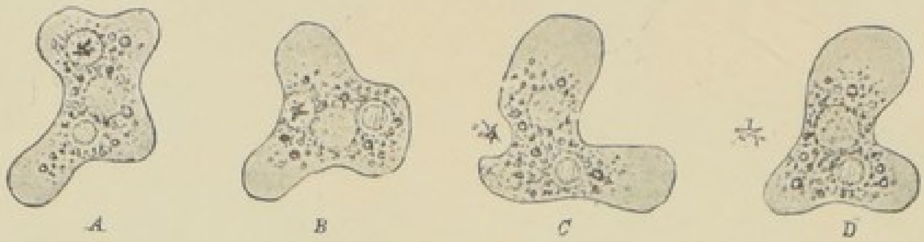


Fig. 6.—An *Amœba* in four successive stages of excretion of the undigested residue of food. (After Verworn.)

and carbon dioxide, and thus gets all the energy possible. While, therefore, some plants and animals can live in the absence of oxygen, it is only the most lowly organized which can do so, as their energy requirements are small. Some plants can live with or without oxygen; a familiar example is *Mucor*, a mould which grows readily on jam. If *Mucor* be given oxygen it oxidizes the sugar to water and carbon dioxide, but if oxygen be denied it has to content itself with the same change which the yeast plant employs, that is, the splitting of sugar into alcohol and carbon

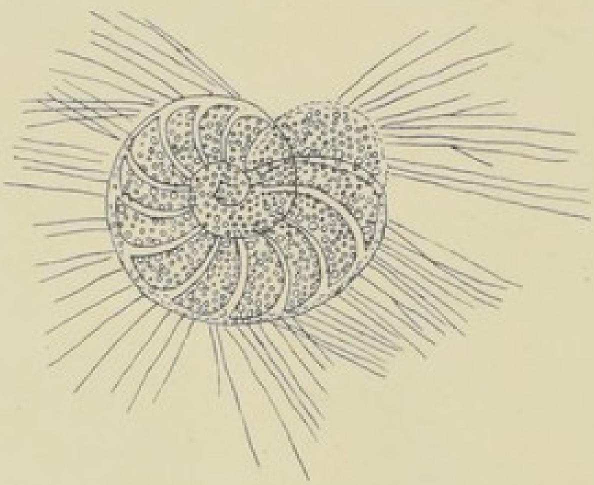


Fig. 7.—*Polystomella*, showing the shell and strands of protoplasm outside the shell. The nucleus is hidden by the shell. (After Schultze.)

dioxide, though much more sugar will have to be broken down to obtain a definite amount of energy than if oxidation were brought into play. All the higher plants and animals obtain most of their energy by oxidation, though non-oxidative changes can also be employed to a slight extent.

But all the energy obtained, whether due to oxidative or non-oxidative change, cannot be transformed into work. This is a well-known law in physics, and it tells us that only a fraction can be so utilized. Coal is a complex, unstable body, and when oxidized (burnt) gives out energy, but very few steam engines turn more than 15 per cent. of this energy into work, the rest appears as heat, which warms the machinery and escapes into the air. The living animal in the same way can only turn a fraction of the energy into work; in the case of the human body about 22 per cent. is so converted, the rest of the energy taking the form of heat, which warms the living substances and escapes. Hence it is that ALL LIVING THINGS PRODUCE HEAT, AND THE MORE WORK THEY DO THE GREATER IS THE HEAT PRODUCED.

We have seen that food is necessary for repair and renewal; we now see that food is also necessary to supply the complex bodies which will liberate energy. The excretions also contain not only the scrap-heap bodies due to repair, but also the degenerated remains of the food taken as fuel.

3. RESPONSE TO CHANGE IN SURROUNDINGS.—A child wishing to find out whether an object is living will prod the object with a stick, or make a loud noise, and then see whether the object moves. In

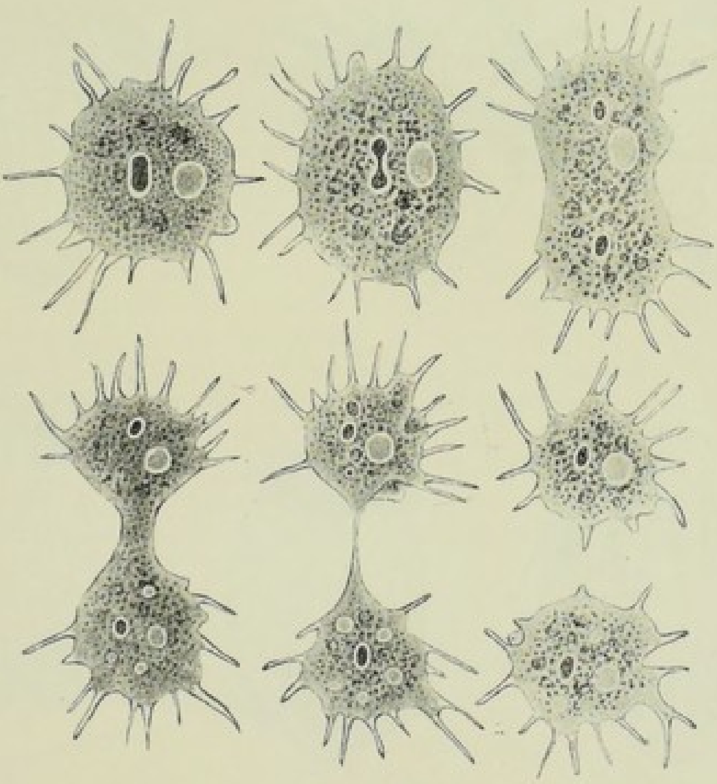


Fig. 8.—*Amœba* in six successive stages of division, showing the elongation and subsequent division of both protoplasm and nucleus, resulting in two *amœbæ*, each with a nucleus. (After Schulze.)

physiological language, the child has applied a stimulus, and the object, if living, will respond to this stimulus. This change in a living animal produced by a change in its surroundings is a most important characteristic of life. The more highly developed an animal is the more able is it to detect changes in its surroundings, and the quicker and better can it respond. Now, this response to stimulus has always a certain character—it tends to preserve the life or the comfort of the living thing concerned. A rabbit prodded with a stick will run away; a dog similarly treated may bite its tormentor; but both with the same object in view. Another feature of this response will be noted, namely, that the response is not limited only to the spot stimulated. This is observable with the lowest animals. Touch one of the tentacles of a sea-anemone, and all the tentacles are drawn in. Even in a single-celled animal a stimulus which irritates one only of its tiny projections of protoplasm may be followed by the cell shrinking and drawing in all its protoplasmic feet. There must be some means, therefore, by which one part of the organism can send messages to the other parts—this mechanism we shall deal with in another chapter.

What changes in the environment are able to evoke a response from the cell?

(*a*) *Temperature Changes.*—If the temperature of the surroundings is lowered, the activities of the cell become sluggish—with rise of temperature a rise of activity occurs. But there is a limit to this response to warmth, for very soon the high temperature destroys the living substance, and causes death. In fact, no living cell can stand the temperature of

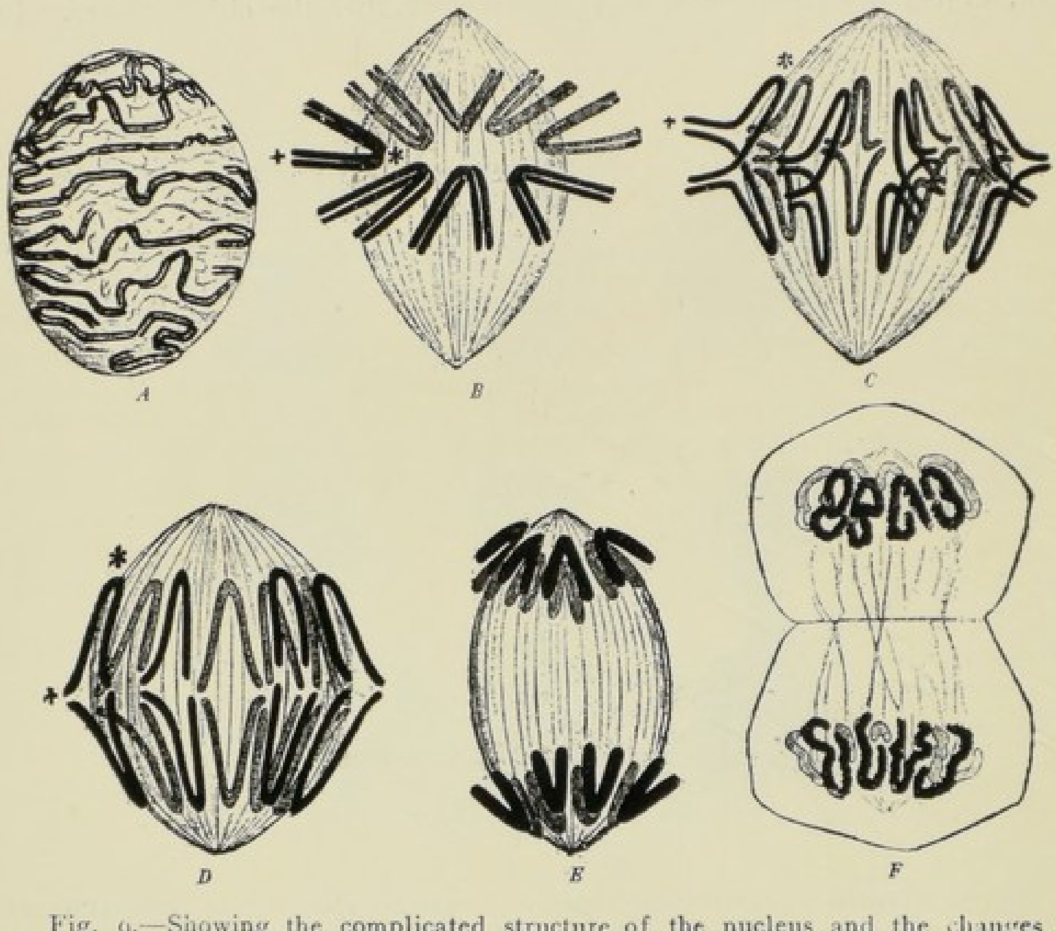


Fig. 9.—Showing the complicated structure of the nucleus and the changes it undergoes on division. (After Flemming.)

boiling water, and most die at 125 degrees Fahrenheit. Heat high enough to injure living substance, if applied to any part of the living substance, acts as a powerful stimulus to that part, and causes a response from the whole organism.

(*b*) *Changes in Concentration of the Surrounding Fluid.*—The changes vary with the cell observed, and need not be described here, only it must be noted that, just as with temperature, there is a limit. High concentrations will kill—witness the *Dead Sea*, and the preserving action of strong syrup; whilst too low concentrations tend to make the cell become water-logged, and finally to burst.

(*c*) *Changes in Light.*—With most cells very strong light acts as an irritant, and often causes death; hence the disinfecting action of sunshine.

(*d*) *Electrical Changes.*—To all cells a sudden change in electrical condition (*i.e.*, a shock) acts as a stimulus, and may kill, if sufficiently great.

(*e*) *Chemical Changes.*—Sometimes we find that cells are attracted by some chemical substance, or have their activities heightened. Many cells move away from irritating chemical bodies. Most substances which chemically injure living bioplasm act as stimuli.

(*f*) *Mechanical Changes.*—Alterations in vibration or pressure may call forth a response. Local pressure, if intense enough, always acts as a stimulus.

4. DEFENCE.—Living bioplasm is, as we have seen, readily disturbed or killed by changes in the surroundings, and all living things have living enemies. The lower in the scale living things are, the more readily and in greater number do they succumb to such changes and attacks, but in the lowest forms there is always some attempt at defence. Many single-celled animals clothe themselves with a hard shell (see Fig. 7); most living things capable of movement try to escape from injurious surroundings. It is probable that in all animals there is, in addition, a chemical response in the living bioplasm, by which antidotes are produced when the poison is derived from another living thing. This will be discussed more fully in the chapter on the blood.

5. GROWTH AND REPRODUCTION.—Most living things start life small, and grow larger; but all living things reproduce their species. A single cell may divide into two in the manner indicated in Figs. 8 and 9, or its bioplasm may break up into a large number of very small spores, each of which is capable of growing into an individual cell. There are many other forms of reproduction, but throughout the whole realm of life the law holds THAT EVERY LIVING INDIVIDUAL IS THE OFFSPRING OF ANOTHER INDIVIDUAL, AND THAT EVERY CELL HAS ARISEN FROM ANOTHER CELL. This is a very important principle, which has now a wide practical application. If a food-stuff (meat, milk, fruit, &c.) is heated to destroy all living germs, and then sealed in an air-tight vessel, no life can develop in it, and, in consequence, the food *keeps*. If any form of life—for instance, bacteria—should be found in such a packet, as would be evidenced by the putrefaction of its contents, we know that either the germs were not all destroyed at first, or that life has come in from without by means of a leak in the vessel wall.

6. MEMORY AND INTELLIGENCE.—A locomotive running into a snowdrift will rebound, and then charge the obstacle again; a second rebound will then take place, to be followed by another charge. This will go on until the steam is exhausted or turned off by the driver. But if a living cell moving about meets with an obstacle it may charge it once or twice in the same manner, yet, sooner or later, it alters its direction of attack, or simply tries to find a way round. This reaction, which has been called the method of TRIAL AND ERROR, implies the existence of MEMORY in the cell (*i.e.*, it can remember its failure), and also of INTELLIGENCE, for it tries a new way of getting over the difficulty.

Animals are marked off from plants by the possession of these faculties in a much greater degree. The higher in the scale of life an animal is the wider is its range of memory and intelligence. It is in mental characters that man is so far apart from the mammals nearest to him (chimpanzee, &c.); in other respects the differences are trivial.

CHAPTER II.

Mammalian Tissues.

The lowest form of life is, as has been stated, the single-celled plant or animal. The bioplasm of such a cell carries out manifold functions; at its sur face food for fuel and repair is absorbed and waste products are excreted; it prepares ferments and chemical antidotes against certain poisons as we shall see later; it is contractile and can propagate the disturbance caused

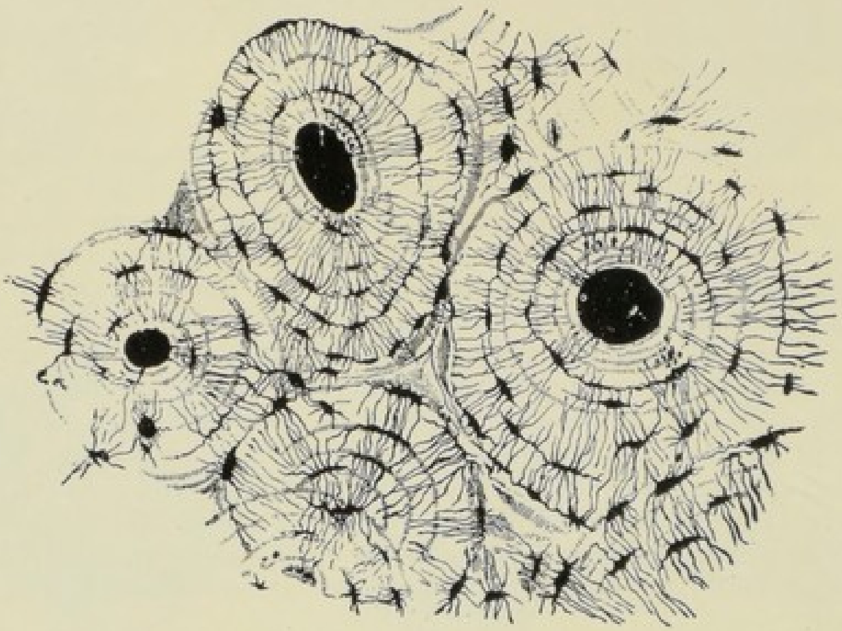


Fig. 10.—Bone showing the tube systems cut across; the bone cells with their prolongations (coloured black) lie between the tubes. The space in the centre of each system contains blood vessels and nerves. (After Sharpey.)

by a stimulus; it can also store food to some slight extent. The animals and plants next in order to these single-celled beings are those which may be looked on as colonies or communities of cells. But in such a colony there is a certain specialization of labour; one set of cells, for instance, may be concerned chiefly with the capture of food, and may allow the other qualities of its units to remain in a backward condition. Another set may have chiefly to do with the locomotion of the entire colony. As we proceed upwards in the scale of life, and especially is this the case with animals, we find that the collections of cells become larger and more differentiated and each set of cells more dependent on all the other sets, so that its units die if cut away from the main mass. When in such a collection of cells we find that the reproductive function is specialized, when from one cell (egg or spore) there can arise not only reproductive cells but cells representing all the various sets present in the complex, then we can no longer regard this complex as a mere community—it has become a single individual.

As we proceed upwards in the evolutionary scale we find then that new groups of cells are marked off from their fellows to carry out some function, and that the other cells of the animal body are relieved of this

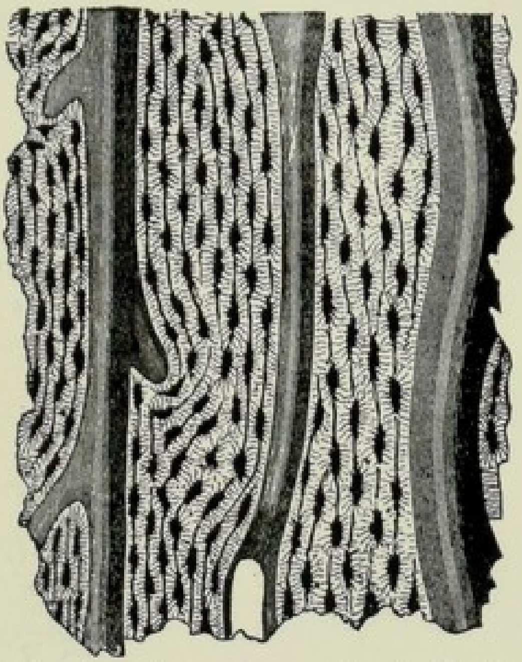


Fig. 11.—Bone showing the tube systems cut longitudinally. (After Rollett.)

function. This division of labour makes greater efficiency possible, for the whole time and material present in each cell can be applied to the performance, not of many duties, but of one only or, at least, a few. Thus we

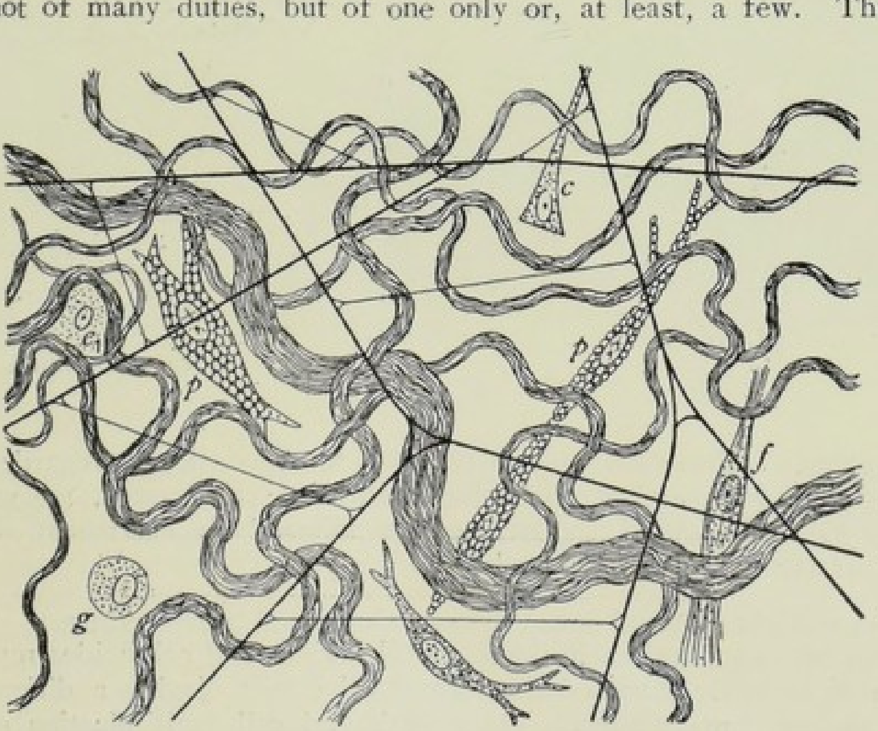


Fig. 12.—Areolar tissue. The white fibres are seen in wavy bundles; the elastic fibres form an open network. (After Schäfer.)

find in muscle a number of cells so altered that contractility is the chief or only function which they retain, whilst other powers have been suppressed. Each muscle cell can contract, and contract more forcibly than any single-celled organism, but only when waste material is removed, when it is shielded from injury, when it is kept at the proper temperature and washed with a solution of the proper concentration and chemical composition—and all by the labour of other cells, which, in their turn, are arranged in groups, each group carrying out some single or simple set of functions, and all of them forfeiting the power of contractility.

Such a division of labour finds a parallel but by no means so perfect in communities of men. The higher the civilization the greater is the specialization of duty, and the more dependent is one group on another. We can see at the present day that the tendency is for men not only to apply themselves to one trade or profession, but to specialize in it, whilst other parts of the same calling are specialized in by other men, and all the time the other necessities of life are being attended to by other groups of

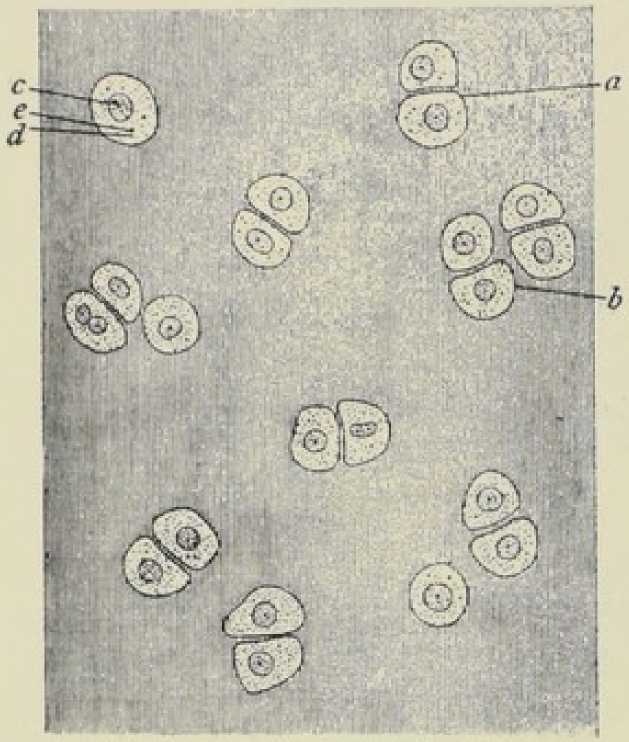


Fig. 13.—Ordinary cartilage. (After Schäfer.)

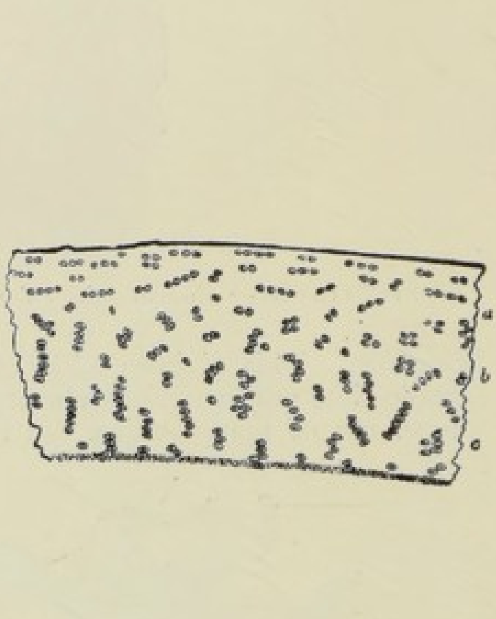


Fig. 14.—Cartilage at the end of bone entering into a joint.

specialists. Now just as this tendency to specialize is regarded as an essential and a proof of advancing civilization among men, the same tendency to specialize amongst cells of the animal body has meant advancing organization of the body or evolution.

Every higher animal starts life as a single cell (fertilized egg). The cell divides into two, and each daughter cell divides and subdivides repeatedly. Even at an early stage of development the cells display a differentiation into two or three groups. As growth and cell multiplication continue, more and more differentiation is discernible until, in the mature animal, the differentiation reaches its limit for that particular species to which the individual belongs. The structures, therefore, which are found in the animal body may be classified according to the type of cell of which they are composed—in other words, may be classified into TISSUES.

Connective Tissues.

The cells in a particular group, relegated to a particular function, could not act properly unless supported and held in position. Moreover, each group must retain its proper place and not be liable to any great alteration in position or shape. We find then that between cell and cell there is always a cementing substance or INTERCELLULAR SUBSTANCE even when the cells are apparently in close contact. This intercellular substance, though outside the cells, has been derived originally from cells. But such a union is not sufficient for the body's needs, and thus it comes about that certain tissues are set aside to act in a purely physical manner, to support and bind the cells of active tissues together, to hold organs in position, and to give rigidity and elasticity where such is required. Such tissues are connective tissues, and in them we find that the intercellular substance is often in great excess of the cell proper though dependent on the latter, for, if separated from its cell, it undergoes degenerative changes. The cells in connective tissues have no special function to perform, except to nourish and to maintain the physical condition of the tissues; their activities therefore are small.

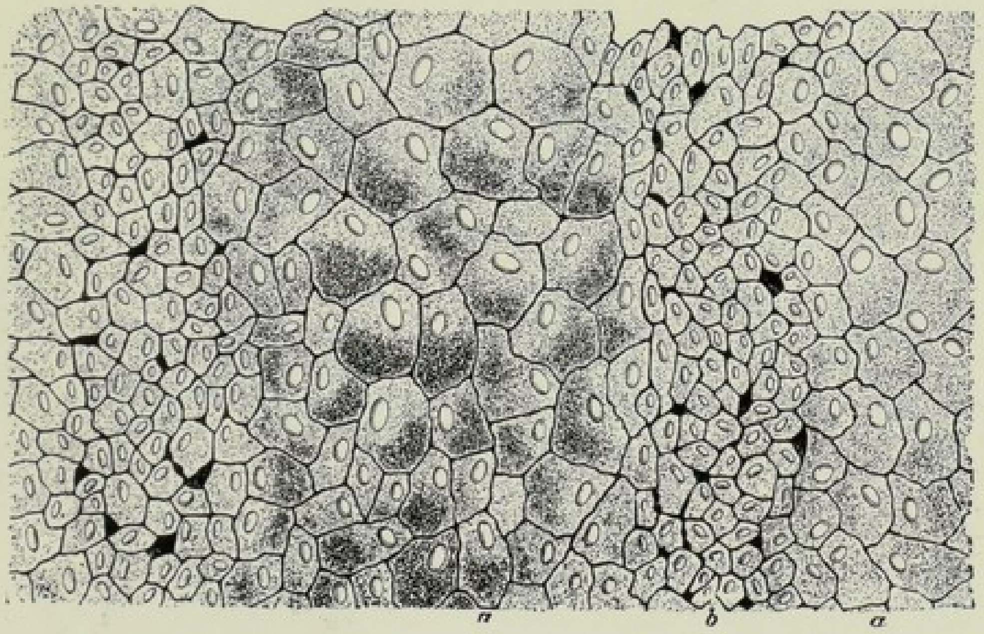


Fig. 15.– Endothelium. (After Klein.)

In FIBROUS TISSUE such as we find in tendon (sinew), the intercellular substance is composed of fine fibres which, though readily bent, are extremely tenacious and almost unstretchable. If the fibres are densely interwoven and spread out to form a flat membrane such a tissue can act as an envelope or tough capsule, as in the eyeball, testis, &c. In BONE we find fibrous sheets, some forming a series of tubes one inside the other, some running from one set of tubes to another, and each bolted to its neighbour by fibrous pegs like layers in the sole of a boot. Even this dense and well riveted tissue is not rigid enough for the body's needs, and so mineral salts, such as calcium and magnesium phosphates, are precipitated through and through the fibrous sheets.

The DENTINE or ivory of teeth is composed of very minute tubes of fibrous tissue which lead from the tooth pulp to the inner side of the enamel, and, like bone, are hardened by deposition of mineral salts.

In ELASTIC TISSUE the fibres have a different chemical constitution which confers on them very different properties—they are highly elastic in the sense that indiarubber is elastic and, in consequence, this tissue is found in parts where frequent stretching is necessary without producing a permanent change. All the larger quadrupeds have a strong band of elastic tissue (*ligamentum nuchae*) running from the head along the back

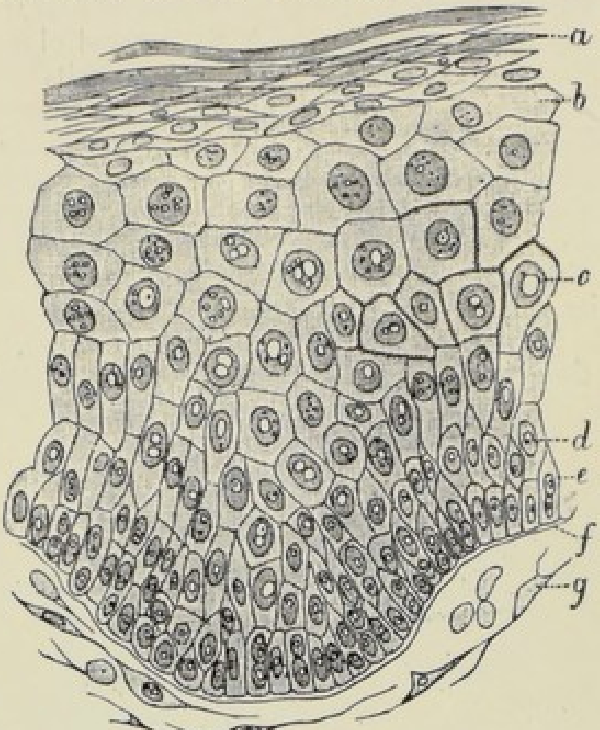


Fig. 16.—Section of skin. (After Cadiat.)

of the neck and firmly joined to the spine. This ligament saves the animal a great amount of muscular exertion by helping to keep the head up or to raise it when lowered. Elastic tissue is also found in the arteries which are subjected to varying pressures of the blood within.

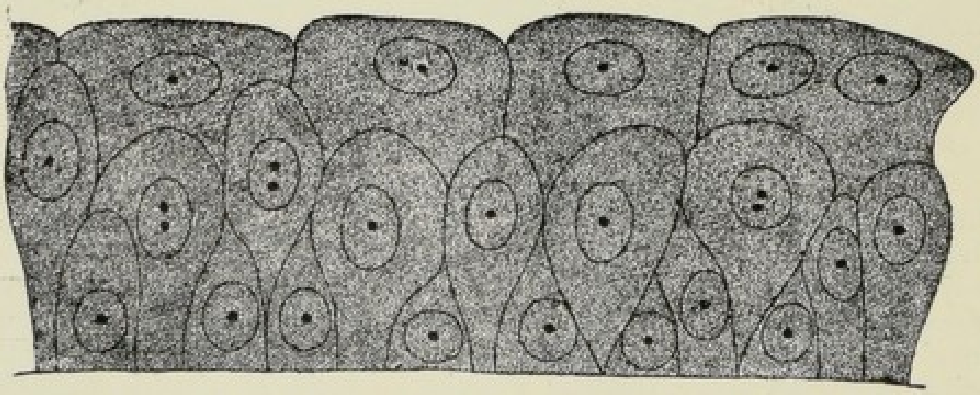


Fig. 17.—Section of the lining of the bladder. (After Schäfer.)

When the intercellular substance is composed of a very loose network of fine fibres, some elastic and some fibrous, the tissue is called AREOLAR. Areolar tissue is admirably adapted for holding in its meshes the active cells of other tissues; it enters into every muscle and nerve, supporting the cells and collecting them into bundles. It also enters into every gland, binding the lobes of the gland together.

CARTILAGE, or gristle, is really a form of fibrous tissue, though in some forms the fibres have lost so much of their distinctiveness that the intercellular substance looks transparent and glassy. In a few parts of the body, as in the pads between the bones of the spine, fibres are present, and are elastic. In all forms of cartilage the cells are fairly numerous, and fibres, when they can be seen, have only a short course. Cartilage functions as a pad with a smooth surface on the ends of bones when these take part in forming a joint; it is also of use where some rigidity is required, but where a certain amount of flexibility must also be retained. Thus the ribs are joined to the breast bone by cartilage, the external ear and the nostrils retain their shape by it, and the windpipe is kept open by rings of this tissue.

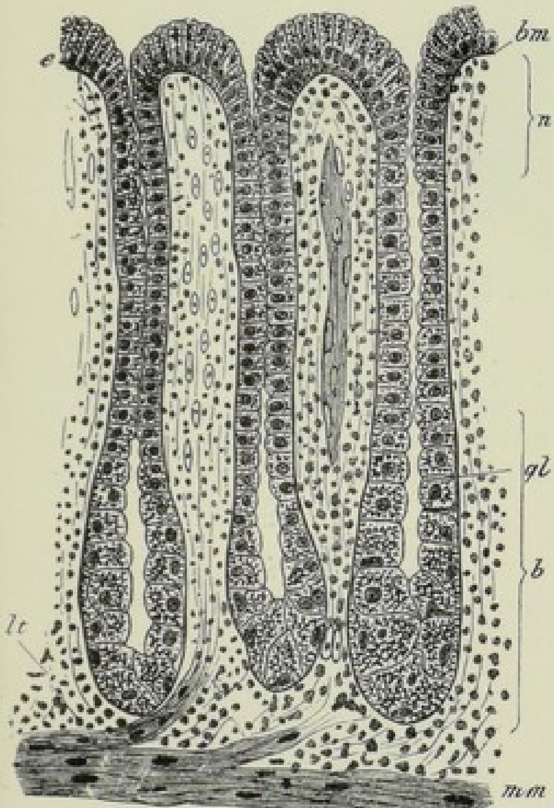


Fig. 18.—Section of mucous membrane of stomach showing simple glands. (After Schäfer.)

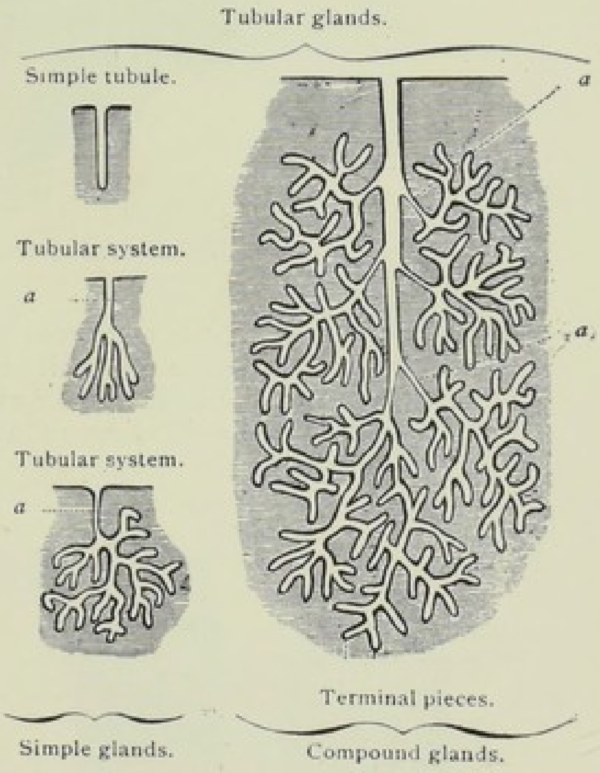


Fig. 19.—Simple and compound tubular glands. (After Stöhr.)

In all connective tissues there are spaces, some like long tubes, but mostly irregular in shape. The spaces are lined by ENDOTHELIUM, which consists of a membrane formed of flat cells one layer deep.

Epithelial Tissues.

Epithelial tissues are composed of cells with well-defined nucleus and a protoplasm that does not branch. The cells are never completely isolated one from another, and as a rule but little connective tissue is found in epithelial structures. In the skin and in the lining membrane of the gullet, tongue, and bladder, epithelium forms a membrane composed of several layers of cells; in the lining membrane or *mucous membrane* of the stomach, gut, and breathing passages it is one cell deep, each cell being joined to its neighbours by a small amount of cementing substance.

All glands which form a secretion and discharge this secretion by a duct are formed of epithelium. To understand the structure of a gland it is necessary to know that when epithelium is not merely protective, as it is in the bladder and the skin, it is either *absorbing* materials, as in parts of the food canal, or is *secreting*, that is to say, is manufacturing

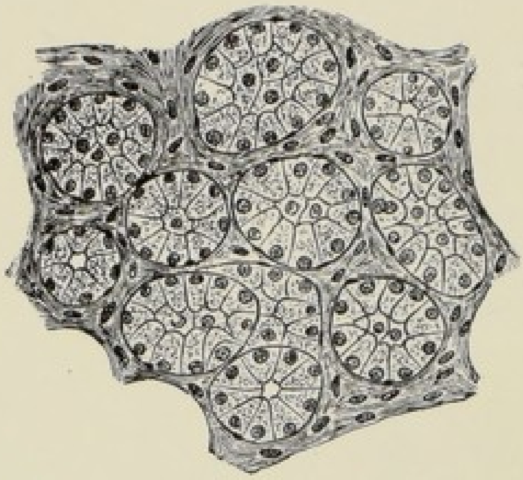


Fig. 20.—Typical section through gland. (After Harris.)

some substance out of the nutriment supplied by the blood, and is pushing this substance outside the cell walls into collecting tubes or ducts. Each gland may, in fact, be looked upon as a factory for the production of some special material ; the epithelium of a salivary gland, for instance, secretes

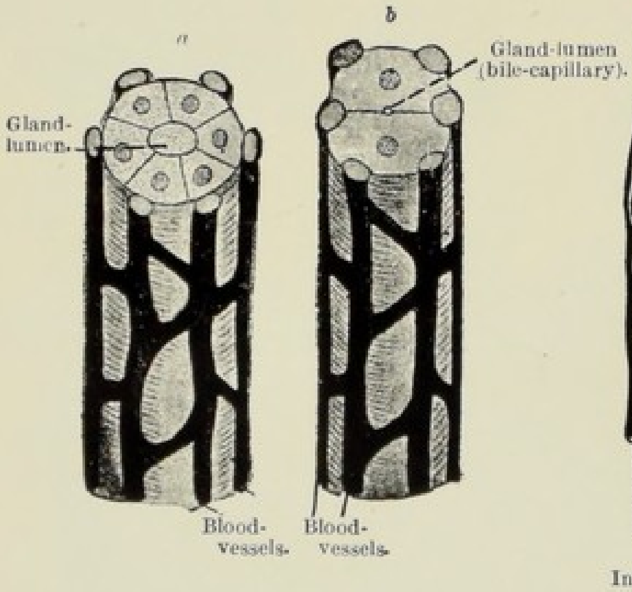


Fig. 21.—(*a*) Scheme of a segment of a terminal piece of an ordinary tubular gland. (*b*) Scheme of a segment of a terminal piece of the liver. (After Stöhr.)

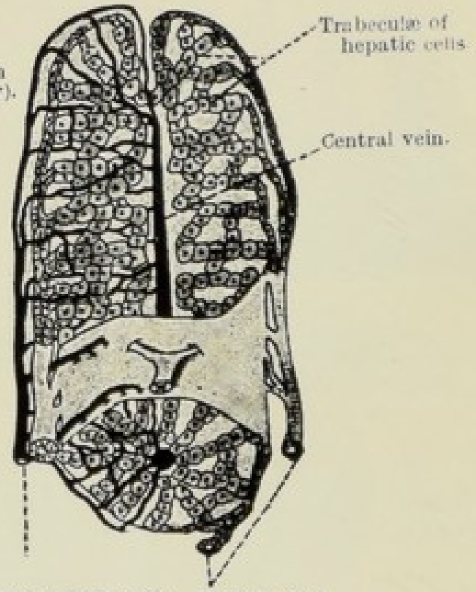


Fig. 22.—Scheme of liver lobule. (After Stöhr.)

saliva, the liver secretes bile, the lachrymal glands secrete tears, &c., &c. It does not follow, therefore, that the functions of all epithelial glands will be the same, even glands which are remarkably alike under the microscope may manufacture totally different substances.

Now, if a secretion has to be poured on a surface which is limited in extent a great increase in the number of active cells can be effected if portions of the surface are dimpled. This dimpled epithelial surface is in reality a gland, and is found as such in the inner wall of the gut and part of the stomach. But this process of dimpling can go much further, and the tube can be coiled as in the sweat glands, or branched as in the testis, or branched and with pockets on the branches as in the salivary and mammary glands and pancreas. A cross section through the tube or pocket gives the characteristic appearance shown in Fig. 20. The liver is in reality a gland of the second variety (branched tube) though here the structure is more complex than with glands generally.

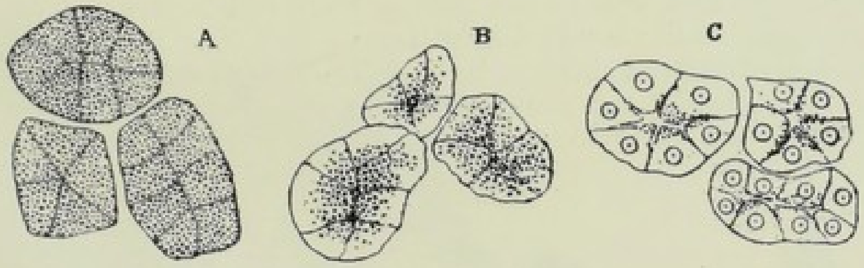


Fig. 23.—Gland cells. (*a*) At rest. (*b*) After a short period of activity. (*c*) After a long period of activity. (After Langley.)

The secretions from these glands pass along ducts which are lined by a single layer of epithelium. In all cases the glands can be divided into lobes and the lobes into lobules, which are really terminal branches. Lobules are held to lobules and lobes to lobes by connective tissue.

The progress of secretion in a gland can be followed under the microscope. In a gland which has not secreted for some time the cells can be seen to be filled with granules which represent material ready for a rapid change into the special secretion of the gland; when the gland is stimulated

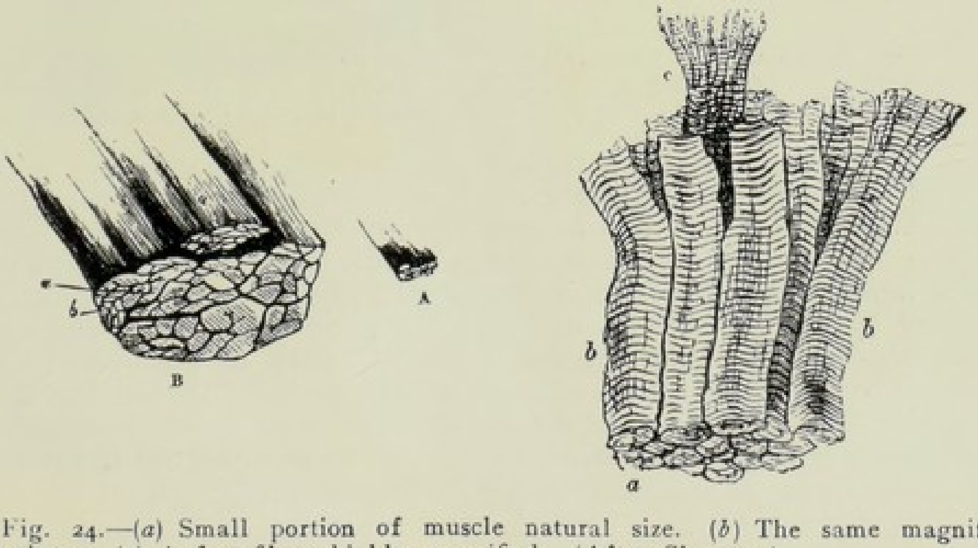


Fig. 24.—(*a*) Small portion of muscle natural size. (*b*) The same magnified five times. (*c*) A few fibres highly magnified. (After Sharpey.)

into activity the granules diminish in number whilst secretion is poured into the space or lumen between the cells. If a gland be stimulated to exhaustion no granules are visible, but on letting the gland rest the granules are built up anew from the nutriment brought by the blood.

Epithelium, when it forms skin, hair, nails, tooth enamel, horn, feathers, scales or transparent parts of the eye, is devoid of blood vessels, but glands composed of this tissue are richly supplied.

Muscular Tissues.

The essential elements in muscular tissue are cells in which the faculty of contractility is carried to a high degree of perfection. There are three types of this tissue from a functional as well as a microscopic stand-point. In the muscles attached to bones and which are under the control of the will, hence called *voluntary* or *skeletal* muscles, the cells are long, thin, unbranched cylinders which show a well marked cross striping, and have each a nucleus placed well to one side. Each cell is enclosed in a thin sheath of connective tissue which insulates one cell from another and helps to form the attachment to sinew or bone. The muscle fibres, formed of the cells and their sheaths, are grouped into bundles by means of connective tissue strands which carry blood vessels, nerves, and a variable amount of

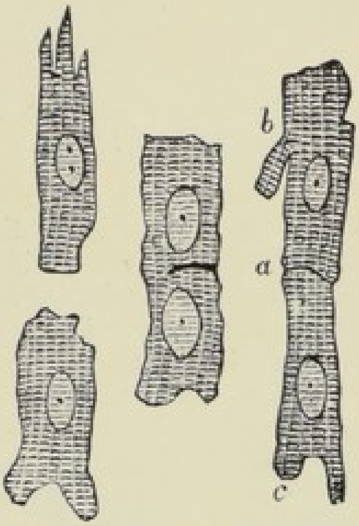


Fig. 25.—Muscular fibre cells from the heart. (After Schäfer.)

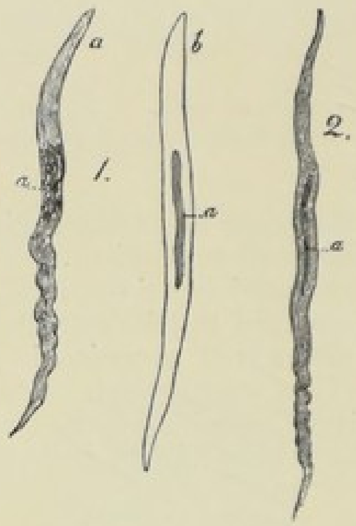


Fig. 26.—Muscular fibre cells from the muscular coat of the small intestines—"smooth muscle." (After Schäfer.)

fat. A second form is *heart muscle;* here the cells are short and squat, have branches which unite with neighbouring branches, and have their nuclei in the centre. Like skeletal muscle cells they show a well marked cross-striping. A third form is *smooth* or *involuntary* muscle which is concerned with the movements of those organs such as the stomach, gut, bladder, uterus, &c., which are not under the control of the will. The cells here are short in length and taper at both ends. The nucleus is in the middle, and is elongated in shape. In both heart muscle and smooth muscle connective tissue carrying nerves, blood vessels, and fat is present, but it never forms an insulating sheath for the contractile cell.

Lymphoid Tissue.

This tissue, as it is found in the spleen, tonsil, lymph glands, &c., is simply areolar tissue packed with small round cells. The full significance of organs composed of this tissue we are far from understanding, the little that is known will be given in the chapter on the ductless glands.

Fat or Adipose Tissue.

With the exception of a connective tissue framework which carries blood vessels and nerves, adipose tissue is composed entirely of cells, in each of which an accumulation of fat has occurred to such an extent that the nucleus, with only a small amount of protoplasm around it, is pushed to one side.

Fat acts as a valuable store of fuel food; it also serves as a padding filling up spaces, and so holding organs in position and shielding them from injury; under the skin it forms a non-conductive layer which prevents the heat of the body from escaping too rapidly.

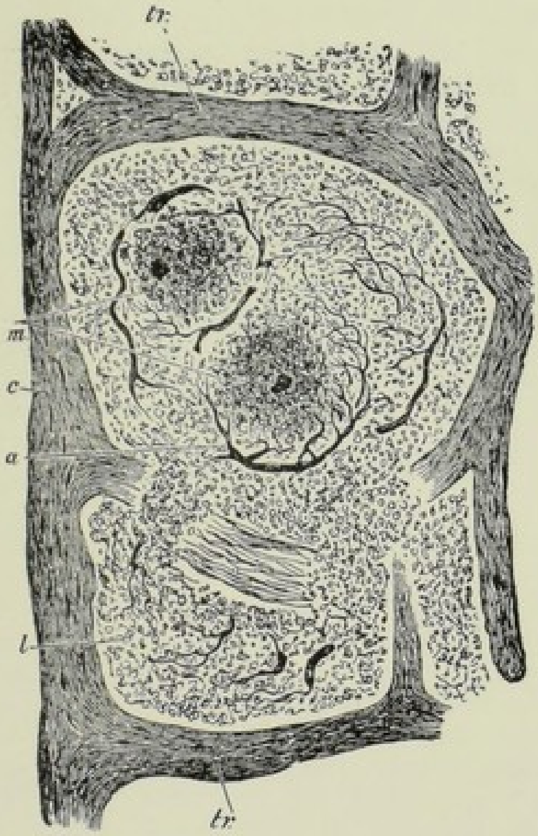


Fig. 27.—Section of spleen showing lymphoid tissue. (After Schofield.)

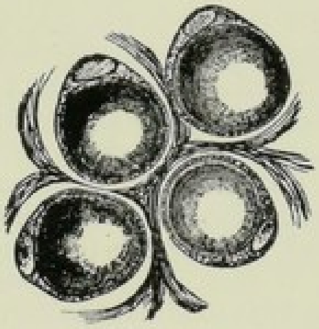


Fig. 28.—Fat cells, showing nuclei at the side. (After Klein.)

The blood, which is generally reckoned as a tissue, and the structures present in the nervous system, are so specialized and important that a description of them had better be deferred until their functions are dealt with.

CHAPTER III.

Hornome and Nerve.

When certain cells in an animal body have been specialised to carry out a certain function, we rarely find that they are scattered singly over the body. As a rule, they are grouped into masses, and constitute the active part of organs. Thus the cells that secrete tears are found clustered together to form the lachrymal or tear glands; cells that have specialised as regards contractility are massed into well defined muscles, etc., etc. In all such structures, it is necessary to remember that there is present not only the active cells set aside for a particular duty, but also a framework of connective tissue to support these cells and to preserve their relative positions and to give a certain amount of rigidity or tenacity to the mass. Moreover, there must be arrangements present by which nutriment is brought both to acting cells and supporting structure and by which waste matter is removed. Then in those organs (glands) which form a secretion, there is usually a duct system by which the secretion is carried to that part of the body where it is of use. It will be at once obvious that, if such cells were to act irregularly and spontaneously and without regard to what is going on in the other parts of the body, the latter as a whole would be incapable of carrying out any individual function. We find, on the contrary, that the active cells of the body are under a stern discipline; they must work at the right times and with the proper intensities; they must start, quicken, slow down, or stop, when ordered to do so and only when so ordered. Were this discipline infringed, and were an organ to act on its own initiative merely, there would not only be a waste of energy, but also an interference with the functions of the other parts. A copious and unnecessary secretion of tears would render distinct vision impossible; a stoppage of the normal supply would mean destruction of the eye; muscular movements, especially of the heart or alimentary canal, departing in a very small degree from those prescribed would assuredly be fatal. We find, on regarding the ascending scale of life, that the more specialisation has occurred the more rigid is the discipline and the more dependent is one set of cells upon all the others. In the mammalian body we can point only to one variety of cell, namely, the white blood-corpuscle, which, at the first glance, looks as if it preserved the old and solitary independence of the amoeba. But, when we see these white cells flocking to a region where bacterial enemies have entered and there giving battle and dying in myriads before the assailants are repelled, we understand that they too work for the common weal and are obedient to command. This specialisation and disciplinary system has brought with it in the course of evolution a certain disadvantage for, should one set of cells cease to act properly through injury on any other cause, the whole community of cells would suffer. Thus in the higher animals the delinquency of quite a small set of cells may subject all the others, though wholly faultless, to the extreme penalty. This is a frightful wastage of living matter, but it is the price we pay for high specialisation.

To understand how this disciplinary system is maintained we must first of all assume that in each active cell there is not only the special machinery for carrying out the cell's particular function, but also a substance or mechanism called the RECEPTIVE SUBSTANCE, which can receive a message, and be set into action by the message, and by its action influence the machinery of the cell, either increasing (also starting) or diminishing (also stopping) the latter. This receptive substance, although not a part of the special machinery, is still a portion of the cell, and dies when the cell dies. In each cell of voluntary muscle (striped or skeletal muscle) there is only one receptive substance, which in this case can start or augment the activities of the contractile elements of the muscle cell. When such a muscle cell stops contracting, it does so because its receptive substance is no longer receiving any message. The drug curare (South American arrow poison) has this interesting property, that it temporarily destroys the receptive substances of voluntary muscle all over the body, so that, although urgent messages may be sent, the muscles remain uncontracted and useless.

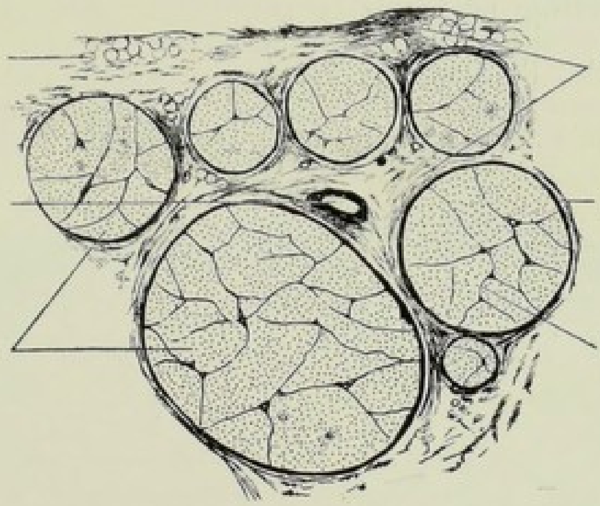


Fig. 29.—Portion of a cross-section of a nerve-trunk magnified twenty times. (After Stöhr.)

That the contractile part of the muscle is not affected can be shown by stimulating the curarized muscle with electricity, when a vigorous contraction can be evoked. Hence it is that in an animal poisoned by this drug all movements, including breathing, cease, and death occurs through asphyxia, though the muscles themselves remain as powerful as ever.

In the cells of involuntary (smooth) muscle and heart muscle, and in the cells of most secreting glands, we find two receptive substances, one which can start or quicken, and the other which can slow down or stop. It must be clearly understood that each receptive substance is fitted for a particular mechanism; no matter how the receptive substance is set into action, it always acts in the same way on the cell mechanism, either to depress or to augment its activity.

So far as physiologists have been able to discover, there are but two methods by which a receptive substance may be set into action. The first is through the agency of a chemical substance, or HORMONE, which travels in the blood stream, and so reaches eventually the cells to which it is destined; the second method is that of the nervous system.

The Hormone.

No more instructive instance of hormone action can be given than that which is responsible for the activities of the pancreas, a gland which pours its digestive secretion into the first part of the intestine, not far from its commencement at the stomach. Now, the contents of the stomach (fourth stomach of ruminants) are acid in reaction, and when this acid mixture leaves the stomach and enters the small intestine, the acid present acts chemically on the wall of the gut and produces a hormone, called SECRETIN. This secretin, as soon as it is formed, is caught up by the blood vessels, and is swept along in the blood stream, and so reaches all parts of the body, including the pancreas. When the secretin has reached this organ, at once the receptive substances are stimulated, and the gland begins to pour out its special secretion—pancreatic juice—into the gut, and right into the middle of the acid stuff from the stomach. Now, the pancreatic juice is alkaline, for it contains carbonate and bicarbonate of soda, and thus when enough has been poured into the gut it will annul altogether the acidity of the stuff from the stomach. But it was this acid which formed the hormone SECRETIN, and started it on its travels, so that when there is no longer any acid there will no longer be any secretin, and the pancreas will therefore no longer be stimulated. But soon the stomach will send a fresh squirt of its acid contents into the gut, secretin will be formed by the acid, the pancreas will be stimulated, and the pancreatic juice will keep pouring into the gut as long as there is any acid left unneutralized. By this automatic mechanism the pancreas will start acting at

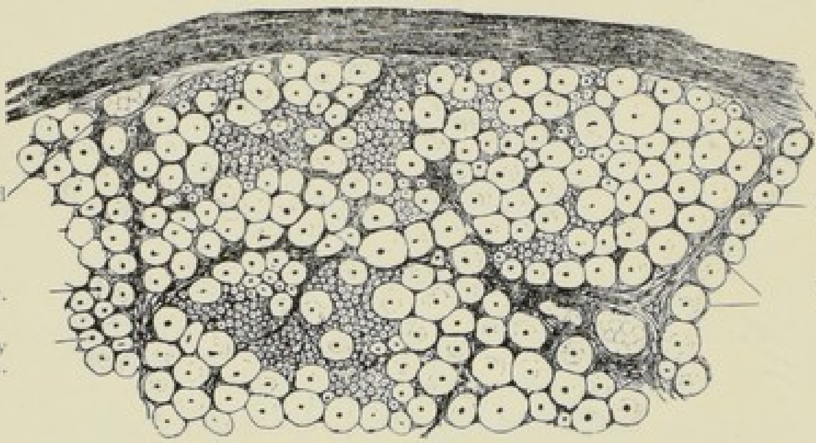


Fig. 30.—Portion of a cross-section of a nerve trunk magnified two hundred times. (After Stöhr.)

the right moment, namely, when food enters the intestine from the stomach; and with the proper intensity, which will depend on the strength of the acid; and for a sufficient interval of time, namely, until the acid has been neutralized, for until this has been effected the digestive ferments in pancreatic juice cannot come into play.

We know of many other hormones which are at work in different parts of the body. The profound changes that occur in both sexes as a consequence of puberty, and the alterations in the mammary gland (udder) during pregnancy, are instances of hormone action.

Of the chemical constitution of the hormones but little is as yet known, only one true hormone, namely, ADRENALIN, a substance produced in small organs situated near the kidneys, and hence called adrenal or suprarenal, glands, having been identified by the chemist and prepared in the laboratory. But secretin and the hormones produced in the reproductive organs and in the thyroid gland in the neck, &c., have so far baffled the chemist's researches, chiefly because they are present in the body in such extremely small quantities that to prepare an amount sufficient for an

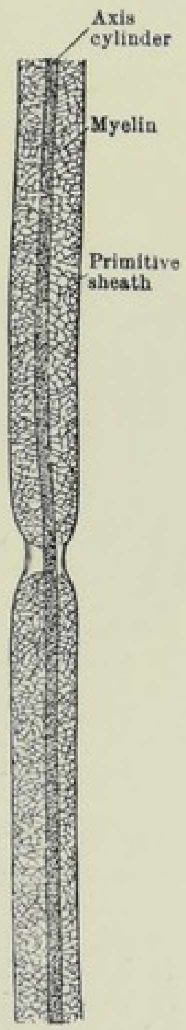


Fig. 31.—Nerve fibre showing axis cylinder and insulating material (medulla or myelin). (After Kölliker.)

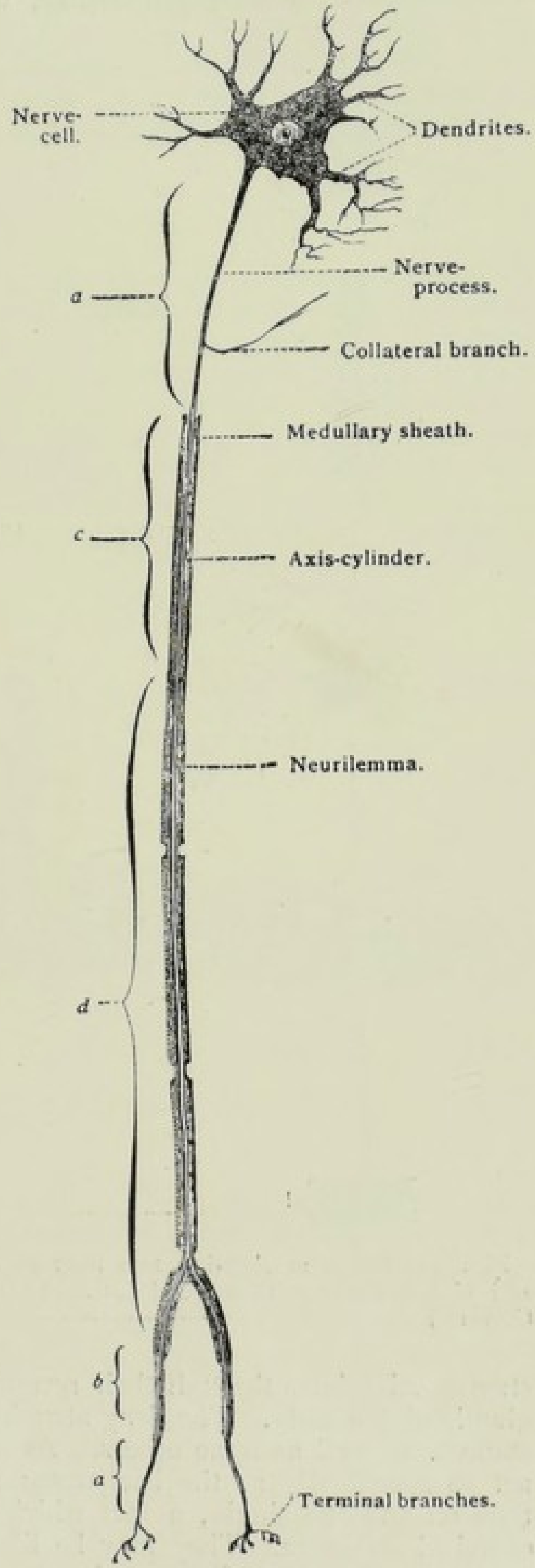


Fig. 32.—Diagram of a neuron (After Stöhr.)

exhaustive analysis is at present impossible. We know this, however, about hormones that they are all comparatively simple bodies; some of them are probably closely allied to certain vegetable alkaloids, and to this similarity in structure we may ascribe the medicinal properties of the alkaloids. For instance, the drug pilocarpine, when it gains admittance to the blood

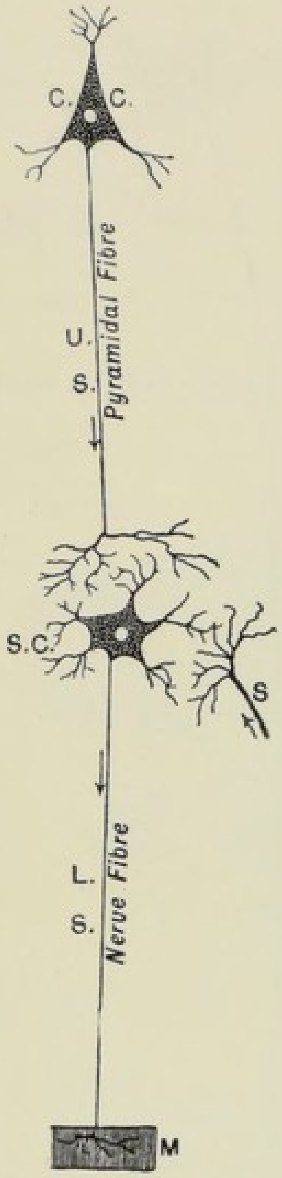


Fig. 33—Diagram showing two neurons S. and U.S. uniting with a third L.S. (After Gowers.)

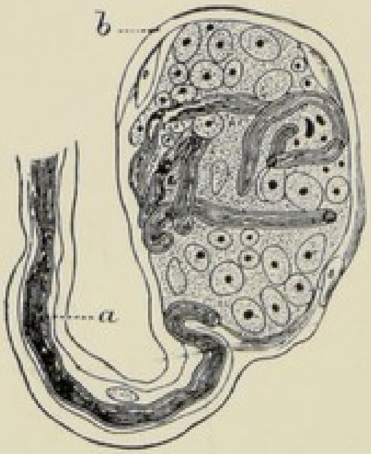


Fig. 34.—Sensory nerve ending in skin.

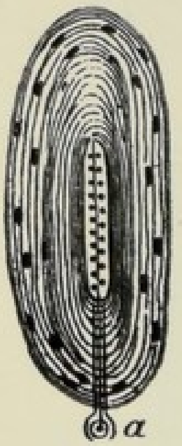


Fig. 35.—Sensory nerve ending in tongue of duck. (After Klein.)

stream, stimulates through their receptive substances nearly all the secreting glands of the body. The drug atropine paralyzes these same receptive substances, as well as some others. As a rule, the vegetable alkaloids do not act so specifically as the hormones; they act rather on groups of organs than on any one singly, a fact which is probably to be explained by their chemical structure. They may be likened to master keys which can open a number of locks; whereas a hormone may be fitted for one lock only.

The automatic mechanisms which employ hormones, though they may be sure, must certainly be slow. The hormone is formed, then caught up by the blood, and then distributed by means of the blood stream to all parts of the body, including the organ which it is fitted to stimulate. This procedure at its quickest is still slow, compared with some of the reactions of the body. The burnt child that touches the fire withdraws its hand in a fraction of a second; were the hand to remain until the heat formed a hormone which, when it reached the muscles of the arm, excited them to draw the hand away, there might be very little hand to take care of. Plainly, there is another system of messages in the body, a system which may be likened to the telegraphic, whilst the hormone may be compared with the letter post. It has been named already—the nervous system.

The Nervous System.

When we cut across what is popularly termed a nerve, but what the physiologist prefers to call a nerve trunk, and examine it under the microscope, we get appearances such as are given in Figs. 29 and 30. The nerve trunk is in reality composed of several thousand nerve fibres, grouped together into bundles. If we examine one of these fibres we shall find in its centre a core, which is concerned with the conduction of the nerve message, and to which the name AXIS CYLINDER, or AXON, is given. Around it we find an insulating jacket, composed of a phosphorized fat, the MEDULLA, or MYELIN, which is, however, not complete, but broken at intervals, as shown in Fig. 31, so that nutriment can get into the axis cylinder.

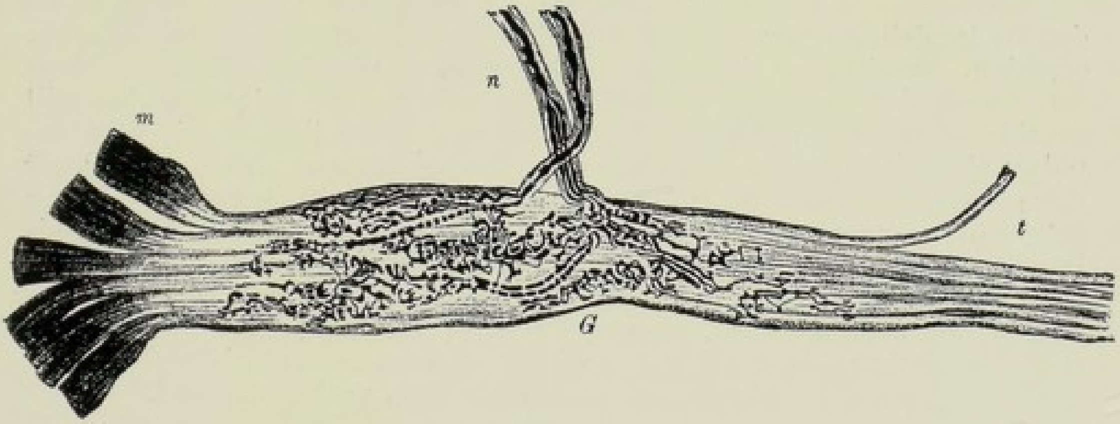


Fig. 36.—Sensory nerve ending in tendon. (After Ciaccio.)

If we choose any nerve fibre anywhere in the body, and follow it along its course, we shall always come in one direction or the other to a nerve cell. In fact, a nerve fibre, or, more correctly stated, the acting part of a nerve fibre, the axis cylinder or axon, is a prolongation from a nerve cell, and is therefore part of that cell. Nerve cells may possess few or many prolongations, but generally one can be picked out which is a typical axon or axis cylinder. Most axons acquire the insulating jacket, or medulla described, and are therefore termed medullated nerve fibres; some, however, do not, and are termed non-medullated nerve fibres. Every nerve fibre contains an axon, and every axon is a process from a nerve cell. To this whole system—the nerve cell, with all its prolongations, axon included—the name NEURON has been given. It is important to have a clear idea as to the neuron, for out of neurons the entire nervous system is built. The nerve trunk cut across, and shown in Fig. 29, contains several thousand axons, each of which is part of a nerve cell. Where the nerve cell is situated will depend on the specific use to which its axon is put.

Now, the function of a nerve fibre, or axon, is to transmit a message, called a NERVE IMPULSE. What the impulse exactly is still baffles all attempts of physiologists to discover. We know that it is not something material which is driven or sucked along; nor is it a chemical change which runs along the axon as fire will run along a train of gunpowder; nor is it an electric current such as runs in telegraph and telephone wires, for its speed is too slow for this—the electric current travels at the rate of some hundred thousand miles per second, whereas the nerve impulse, if given an axon long enough, could never cover more than 65 yards in the same time. All that we can state is that the nerve impulse is a physical change, which runs along the axon without leaving it permanently altered by being so used. A wave travelling along water, a sound travelling through air, a twist running through a long thin strand of jelly, are instances of physical changes, but they are not quite the same as a nerve impulse. That the nerve impulse is not chemical is shown by the absence of any rise in temperature, and by the fact that no waste products can be detected. Moreover, the axon cannot be fatigued; a hundred thousand impulses may pass through an axon in quick succession, and the last be transmitted as quickly and powerfully as the first. The only detectable change in the nerve fibre which accompanies the passage of an impulse is a change in the electrical state of the nerve as tested by delicate instruments. Most probably the impulse is a change in the arrangement of the particles inside the axon, which we know are charged with electricity; when the impulse has passed these swing back into their old positions.

An impulse is very readily started in a nerve fibre; most things which destroy its delicate structure will bring an impulse into being—for instance, crushing, burning, or irritation with corrosive chemical bodies. These may be applied, however, so weak as not to injure the substance, but still capable of starting impulses; thus, tapping a nerve lightly will send impulses along it; electric shocks are very efficient starters also. Now, in all these cases, whenever an impulse is started artificially somewhere in the course of an axon, the impulse travels always up and down, and passes into every branch of the nerve cell. We may here lay down the law that if an impulse be started in any part of a neuron it will travel through every part of that neuron. Now, in nature it never happens (except in accidents) that a nerve impulse starts in the middle of an axon; provision is always made that it shall travel from one end of a neuron to the other end.

Another fact about nerve fibres follows at once from what has been stated in a former chapter. If a nerve fibre be cut, then that portion still in contact with the nerve cell lives, the portion cut off from the nerve cell dies. This fact gives the experimenter a valuable method for tracing the destination of any particular group of fibres.

The nervous system is divided into two parts—the CENTRAL NERVOUS SYSTEM, composed of brain and spinal cord; and, secondly, the parts that lie outside the central nervous system, and to which the name PERIPHERAL NERVOUS SYSTEM has been given. In the peripheral nervous system we meet with four types of neurons—one type which carries impulses *into* the central nervous system (or C.N.S., as we may briefly call it), the other three types being concerned with the passages of impulses *out* of the C.N.S. We shall deal with these in sequence.

ENTRANT or AFFERENT Neurons—that is, neurons which carry impulses into the C.N.S.—are all of the type indicated by A in Fig. 39. The nerve cell is small, and is to be found in a ganglion placed near the C.N.S., but not in it. We find such ganglia near the spinal cord, and called dorsal root ganglia, to be described in a later chapter. The connexion of the axon with its cell by a T-piece is fairly characteristic of this type. If we trace such an axon towards the periphery—that is, away from the C.N.S.—we shall find that it comes to an end in a special organ specially made for the starting of impulses. Let it be at once understood that all these afferent or sensory nerves are the same in nature. They differ, however, in their connexions with the C.N.S., and in the nature of the end-organ or sensory end-organ, which starts impulses in them. The impulses themselves do not differ one from another; what gives them their special significance is their place of origin and their destination in the spinal cord and brain. Each nerve is a mere conductor of nerve impulses, and impulses only differ from each other in intensity.

A sensory end-organ we may look upon as a special apparatus, which will start an impulse in the nerve to which it is attached when it is disturbed

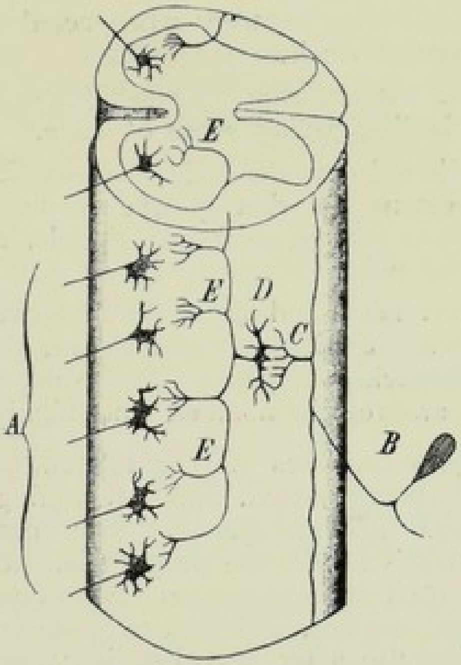


Fig. 37.—Diagram showing how an impulse entering the central nervous system by a sensory neuron DE may pass to the motor neurons A by means of the linking neuron DE. (After Kolliker and v. Lenhossek.)

in a particular manner; we generally find, too, that the end organ is shielded from disturbances which it is not asked to record. Thus we find in the skin of all the higher animals certain end-organs which start impulses when they are warmed. The animal will thus feel the sensation of warmth, and will ascribe it to the part of the skin warmed; but if the nerves coming from these same end-organs were stimulated with electricity, and not heat, the animal would still have the sensation of warmth, and would locate the feeling at the spot stimulated. It is the point of origin and the distribution in the C.N.S., and not the nature of the impulse which determines the nature of the sensation.

A tabulated list of the sensory end-organs may be given as follows:—

(*a*) Confined to the skin, starting impulses—

1. On application of pressure; or at the base of a hair when the hair is moved, giving rise to touch.
2. When warmed, giving rise to sensation of warmth.
3. When cooled, giving rise to sensation of cold.

(*b*) In muscles and tendons (sinews) and ligaments of joints, starting impulses when these are stretched, and therefore informing the C.N.S. as to their condition.

(*c*) In the eye, shielded from heat, and to some extent from mechanical injury, and starting impulses when acted upon by light (or darkness after light).

(*d*) In the ear, starting impulses when acted upon by waves of sound.

(*e*) In the semi-circular canals of the ear (the most important sense organs animals possess). Here impulses are produced by the way in which water lies (or is driven by movements of the head), in a system of arched tubes that run in three directions, and in this way tell the animal the position of its head, and in what direction its head is being moved, and thus allow the body to be kept balanced.

(*f*) In the nose, starting impulses when acted upon by certain gases, giving sense of smell.

(*g*) In the mouth, starting impulses when acted upon by certain soluble chemical bodies, giving sense of taste.

(*h*) Widely distributed over the body, and starting impulses when anything threatens to destroy the structure of adjacent living tissue; hence acting as danger signals, and giving the animal sensation of pain.

(*i*) There are other nerve endings in the body which can start impulses under special conditions—for instance, those telling the animal that its stomach is empty, or its bladder full, &c., &c. These, however, are few in number, and highly localized.

In these end-organs impulses can be started, and in most of them impulses are constantly being started, which, travelling along their respective axons, enter the central nervous system. The course of these impulses through the C.N.S. this is hardly the proper place to describe. It will be sufficient to say that each afferent neuron makes connexion in the C.N.S. with a number of other neurons, and each of these latter with a number of others, so that the impulse after it arrives is carried up and down, and is widely distributed through the C.N.S. The passage of an impulse from one neuron to another takes place at a region called a SYNAPSE, where branches from both neurons interlace. Of the importance of the synapse something will be said later, but one of its peculiarities must be mentioned here, and that is its valve action, which allows impulses to pass in one direction only. Hence it is that no impulses ever leave the C.N.S. by any of the afferent nerves, and, conversely, none can get in by any other channel. The nerve impulses that enter the C.N.S. pass through it in various directions, such directions being determined by the past history of the race (reflex action and instinct), and the past history of the individual (memory and intelligence). They do not lose in intensity by being thus scattered; in fact, they may gain enormously in power, and may last for much greater intervals of time, a change which is effected by the nerve cells of the neurons through which they pass. The nerve cell of the afferent neuron does not influence the impulse; it has, in fact, but few duties to perform, chief among which is maintaining the integrity of the whole neuron; but the cells of the C.N.S. not only preserve the vitality of their axons and other prolongations, but also do actual work by augmenting and prolonging the impulses which pass through them. We must picture the C.N.S. as constantly receiving impulses from its afferent neurons. These impulses pass through and through the dense network of neurons of which the

C.N.S. is composed, blend with each other into special combinations, and finally leave the C.N.S. by exit or efferent paths, of which there are two types—

1. Motor to Voluntary Muscle (Fig. 39B).—The nerve cell is found in the C.N.S., and from it an axon passes uninterruptedly to a muscle; the axon divides up in the muscle substance, and each branch ends by passing into the receptive substance of a muscle fibre.
2. Autonomic Paths. — Each autonomic path is peculiar in that the efferent nerve fibre does not pass uninterruptedly to the organ to be innervated, but ends by branching round a nerve cell which is situated in a nerve ganglion (Fig. 39C). To this nerve fibre the name PRE-GANGLIONIC is given. (In the diagram, for the sake of clearness, the pre-ganglionic fibre is made to branch round one cell only; in reality it branches round several, and so the impulses multiply.) From the nerve cell in the ganglion a nerve fibre (axon) called POST-GANGLIONIC passes into the receptive substance of the cell innervated (Fig. 39D).

It is interesting to note that, whilst the first type of efferent nerves, viz., the motor, passes only to one kind of tissue, namely, voluntary muscle, in the autonomic system, we find that the post-ganglionic fibres can pass to two different types of tissue—

(*a*) involuntary (smooth) muscle found in the walls of the stomach, bladder, gut, uterus, and the various ducts of the body; also the muscles in the walls of arteries and veins and the small muscles attached to roots of hairs (and feathers). Heart muscle must also be included here.

(*b*) Secreting glands, such as the glands of the stomach and intestine, the salivary glands, tear glands, sweat glands, &c.

One very important character about these organs innervated by the autonomic system is that they are not under the influence of the will. An animal can move its voluntary muscles at will, but over heart and artery, stomach, bowel, gland, &c., the will has no power; these organs, innervated by the autonomic system, receive their nerve impulses, therefore, in a purely *automatic* manner, and the number, duration, and intensity of the impulses they receive from the C.N.S. will depend on the nature of the impulses that have gone *into* the C.N.S.

Another striking character of the autonomic system is that whilst it may be divided anatomically into three parts—namely, that coming from the brain (cranial autonomic), that from the spinal cord in the thorax (thoracic autonomic), and that from the lowest portion of the spinal cord (sacral autonomic)—it may physiologically be divided into two parts only, namely, the thoracic autonomic on the one hand, and the cranial and sacral on the other. The thoracic autonomic system has long been known under the name of the *sympathetic system*, from a mistaken idea as to its nature.

We frequently find that an organ is supplied with two sets of autonomic nerves with different functions, one of these sets always being thoracic autonomic, or sympathetic, the other being either cranial or sacral. For instance, the movements of the stomach (stomachs of ruminants) and small intestine are depressed by thoracic autonomics, but excited by cranial autonomic (vagus nerve). The movements of the large intestine are depressed by thoracic autonomic impulses, but excited by sacral. The heart is slowed down in speed by cranial antonomics (vagus fibres), but excited by thoracic.

The salivary glands secrete a copious watery saliva when the cranial autonomics are stimulated, but a scanty and thick saliva when the thoracics are stimulated. The iris dilates under the influence of thoracic, but constricts under the influence of cranial. The arteries in the reproductive organs are dilated by sacral, the arteries of the salivary glands are dilated by cranial, but all arteries of the body except those in lung and brain, which have no nerve supply, are constricted by thoracic autonomic impulses.

Mention may be made here of the fact that the nerve trunks which we find in the animal body generally contain representatives of more than one of the four types of neurons described. Thus, the sciatic nerve contains afferent, motor, and post-ganglionic axons; the vagus nerve contains afferent, motor, and pre-ganglionic axons; nerves connected with muscles always contain afferent as well as motor fibres.

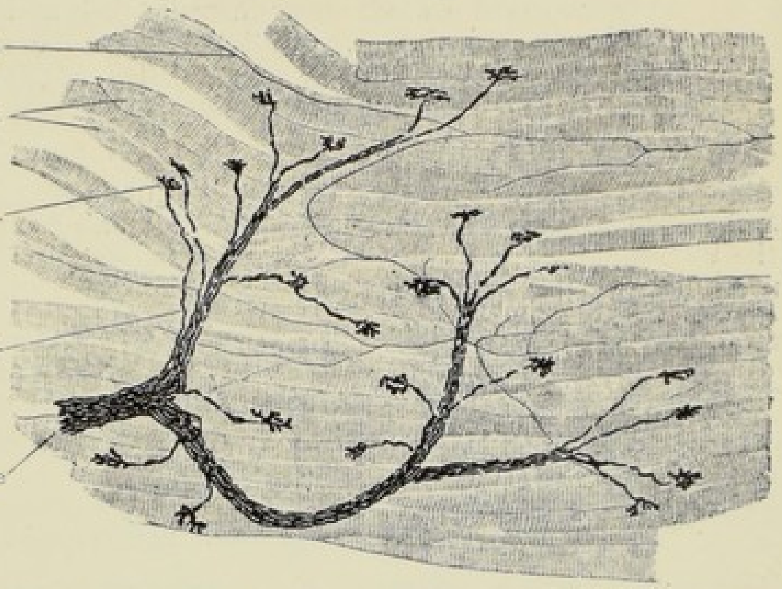


Fig. 38.—Motor nerve-endings in muscle. A few sensory nerves coming from the muscle are also seen. (After Stöhr.)

Reviewing the whole nervous system, we find, first of all, that there are organs in which impulses can be started, namely, sensory end-organs. The impulses thus started travel by means of afferent nerves to the central nervous system. After traversing the C.N.S., and being modified as regards power and duration, they pass out into two sets of efferent paths, one going to voluntary muscle, the other set going to organs over which the will has no control. The central nervous system, though it can modify impulses, apparently cannot create them. If no impulses pass in none will pass out. Even if a limited number of entrant or afferent paths be blocked, some of the exit or efferent cannot be used. If, for instance, the sensory nerves of a limb be cut, the limb cannot be moved by any effort of will—it is as completely paralyzed as if the motor nerves were cut. The same may be seen on a reduced scale when one's fingers are very cold, and in consequence clumsiness of their action ensues. The cold paralyzes the sensory end organs of the skin, tendons, and joints of the fingers, but does not affect the muscles of the forearm which move the fingers, and yet these muscles are partially paralyzed.

This conception of the dependence of outlet impulses on inlet should always be borne in mind. If, for instance, we find that an organ is receiving an unusual rush of efferent impulses, there is generally some alteration in the sensory impulses to account for it. The muscles of the dog's hind leg that are thrown into action when the animal scratches, receive their impulses from the spinal cord, but the original impulse was started at the skin by something tickling the skin. It is interesting to note that the action of scratching, like many other actions, needs only a portion of the C.N.S. to carry it out. A dog which has its spinal cord cut across in the neck will scratch with its hind foot when a spot on the back is tickled, though it feels nothing with its brain, and is apparently unaware of the whole proceeding. The leg of a man whose back is broken across will kick out when the sole of the foot is tickled, and yet the man be utterly unconscious of the action, and unable to move his legs by any effort of will.

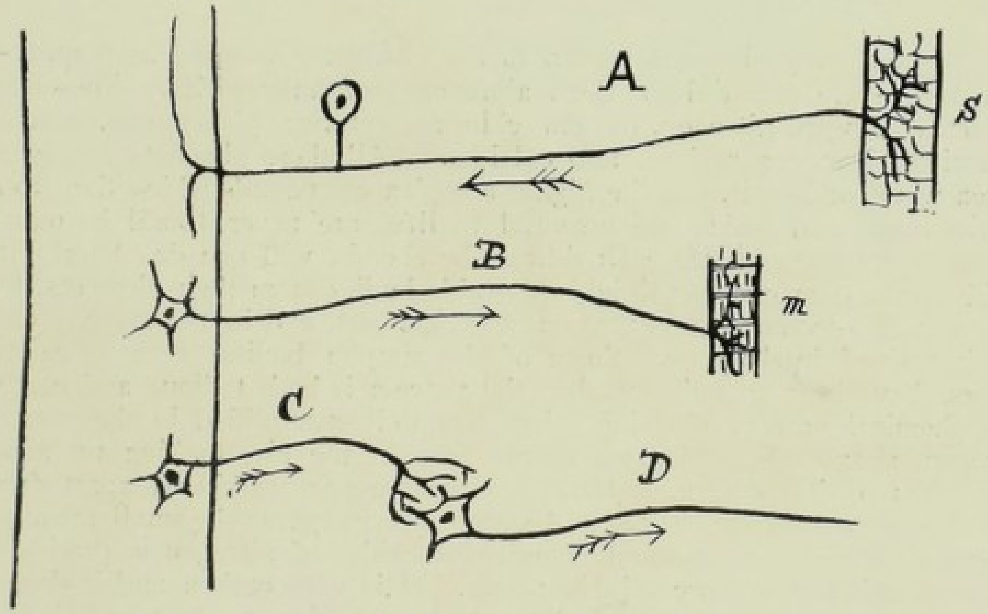


Fig. 39.—Diagram showing the four varieties of nerves carrying impulses into or from the central nervous system. (*a*) Afferent fibre from the sensory surface, *s*, to the central nervous system. The cell is situated in a ganglion close to but not within the central nervous system. (*b*) Motor fibre to the voluntary muscle, *m*. The cell is situated within the central nervous system. (*c*) Preganglionic fibre from cell in the central nervous system to ganglion. (*d*) Post ganglionic fibre from cell in ganglion to involuntary muscle or gland.

There is, however, another method by which the exit or efferent impulses may be modified, and that is by chemical bodies, which influence the nerve cells inside the C.N.S. For instance, in ordinary vomiting the afferent impulses start usually from the wall of the irritated stomach, or from the back of the mouth, pass into the C.N.S., and then out into the muscles concerned in the act of vomiting. In those animals that vomit readily this act can be produced by injecting the drug apomorphine, which operates on the nerve cells concerned with the motor impulses of vomiting, and if it does not start impulses in them, at any rate makes the cells irritable, and responsive to afferent impulses which normally would be far too weak to have any effect. These nerve cells particularly concerned with vomiting constitute what is termed the NERVE CENTRE for vomiting. There are similar centres for breathing, swallowing, &c., which will be dealt with later.

CHAPTER IV.

The Elements of Bio-Chemistry.

Of the many elements known to the chemist—some 81 in number—only twelve are essential for the maintenance of animal life. These are carbon, hydrogen, nitrogen, oxygen, chlorine, sulphur, phosphorus, sodium, potassium, iron, magnesium, and calcium.* All these elements are found in sea water or in soil, but the highly complex compounds which they form in bioplasm, and which are essential to life, are never found in nature except as products of life. Doubtless the chemist will one day be able to build up these complex and highly unstable bodies from their elements, but then only in successive stages, at considerable cost, and by the exercise of a highly-trained intelligence. Some of the simpler bodies, such as certain sugars, have been so built up, but the process is both tedious and costly. The chemical powers of living things are well exemplified in the case of nitrogen compounds. Nitrogen occurs free in the air, making up about four-fifths of its volume, but nitrogen compounds, produced apart from life are present in air, earth, and water only in extremely small amounts. In every thunderstorm a small quantity of oxides of nitrogen is produced, but such oxides never occur in bioplasm. It is with carbon and hydrogen that the cell prefers nitrogen to be linked, and when we find such bodies anywhere on the earth, such as ammonia or sal-ammoniac, we may be sure that living things have been the cause of their formation. Plants have the power of taking up oxides of nitrogen by their roots and of changing the nature of the compound in their active cells, but such a source of combined nitrogen would never suffice for the needs of the many plants that grow on the earth's surface or in the sea. It is to certain bacteria that we must look for the performance of that most necessary task—the "fixing" of nitrogen; that is, the picking up of free nitrogen from the air and the formation from it of such compounds as can readily be used by plants. These nitrogen compounds are unstable bodies, so that if all life were destroyed on the earth, the combined nitrogen would tend in the course of time to become free.

The carbon which is found in bioplasm in the form of complex compounds was originally derived from the carbon dioxide which exists in the atmosphere to the extent of only some three and a half parts per ten thousand. If all life were to cease, these carbon compounds would rapidly break down and revert to the condition of carbon dioxide. As it is, this tendency is constantly in operation. How and where is it, then, that these complex carbon compounds have been built up so that life may be possible? For answer we must look to the vegetable kingdom, and particularly to those plants which are exposed to light and have the exposed parts coloured (generally green). Starting from carbon dioxide and water, these plants

*To this list might be added iodine, which occurs in the thyroid gland, and fluorine, which is found in bone and tooth. The small quantities of silicon present in the animal body may be looked upon as an unavoidable, but harmless, impurity.

can build up complex sugars and starches. But we have seen in a former chapter that it is from the break-down of such complex bodies that living things get their energy. How do the plants at once build up and break down? If breaking down gives off energy, then building up requires energy, and where do the plants obtain this? The answer is from sunlight. This process is taking place all around us wherever there is a green leaf or blade; light is being absorbed, and the energy in the light acting on the carbon dioxide and water is welding them together into the large molecules of sugar or the still larger molecules of starch. Then, from the breaking down of these into the two substances from which they were originally built, energy can be liberated by the plant in different parts of its structure, both to build up the simple nitrogen bodies absorbed by the roots, into the complex nitrogen compounds which we shall shortly study, and to maintain its other manifold activities, such as its upward growth and the raising of its sap.

With animals the case is different; they have no power of building up—they can only break down—and the complex substances which they require have all to be obtained from the vegetable world. Though animals are unquestionably on a higher plane of evolution, they are but poor chemists compared with plants. Plants can link the elements at their disposal, especially carbon, hydrogen, nitrogen, and oxygen, in many different ways, and produce an almost endless series of compounds. Animals, on the other hand, can do very little with the simpler bodies, and have to be content with the linkings which plants have produced. Some few chemical transformations they can bring about, but these are of a comparatively elementary nature. In fact, it pays the animal to get its complex bodies ready made, to be used in growth and in the repair of its bioplasm, and, by their break-down, to furnish the energy which it requires in a much higher degree than the plant. We thus see that animals are parasites on the vegetable world, for, even though some of them get their complex carbon and nitrogen compounds from the bodies of other animals, these, in their turn, live on vegetables or on other animals which do so. But the plant kingdom is not a complete loser by this parasitism, for every animal gives off carbon dioxide, and, therefore, adds to the store of this substance without which light, acting on the green leaf, could produce nothing; again, the excreta of animals, as well as their dead bodies, contain nitrogenous compounds which the plant can absorb by its roots and use in the manufacture of its bioplasm.

In dealing with the special chemistry of animals, it will be as well to include also certain compounds not found in the animal body, but present in the vegetable substances taken as food. The compounds to be studied will be considered under the following groups:—Water, metallic compounds, carbohydrates, fats and lipoid, proteins, and enzymes.

WATER.

The importance of water will be at once admitted when we consider that it is the vehicle which brings nutriment to the tissues and carries waste matter from them; it is the chief ingredient of every cell, and is never completely absent from any part of the body. Deprivation of water kills quicker than stoppage of any other supply except oxygen.

The following table gives the percentage amount by weight of water in a number of tissues:—

	Per cent.		Per cent.
Enamel of tooth ...	0.2	Cartilage	54—74
Dentine of tooth ...	10	Muscles, glands, blood, and brain... ...	75—80
Fatty tissue ...	6—12		
Bone	14—40		

The percentage amount of water in the body as a whole is subject to continual variation; young animals have always a higher percentage than adults, and lean animals than fat. It is, however, safe to state that, on an average, two-thirds, or 66 per cent., of the weight of the animal body is water.

Metallic Compounds.

Chlorides, carbonates and phosphates of sodium, potassium, magnesium, and calcium are found in animal bodies, and are absolutely essential to life.* It is a very suggestive fact that these salts are present in blood in much the same relative proportions as they occur in sea water. In fact, a mixture of one part sea water and three parts pure water, if pumped through the vessels of an organ (for instance, the heart or bowel) which has been removed from a living or recently killed animal, will maintain life in that organ for many hours. A somewhat diluted mixture can keep the heart of a tortoise alive and beating vigorously for some days. On the other hand, we find that any disturbance of the quantities of these salts in the blood (as regards either the total amount present or their mutual ratios), if not promptly rectified by the kidneys, will bring about serious derangements of every living cell in the body. As sodium chloride, or common salt, is the chief salt of the blood, we find animals instinctively endeavouring to keep up the supply; but too much of this substance will be injurious as well as too little, as is seen in the case of castaways who drink sea water. An animal fed exclusively on maize grains will soon be afflicted with muscular weakness and other troubles indicative of calcium starvation; the same often follows from exclusive oatmeal feeding.

How far these actions of salts are due to their combination with the nitrogenous ingredients of bioplasm, and how far to their electrical state, we do not at present know. This, however, is certain, that their presence in a fixed quantity and proportion is an absolute essential of life.

Another metallic compound which, unlike the foregoing, can hardly be called a metallic salt is the compound of iron which exists in the blood, and to which blood owes its red colour. Iron is so widely distributed in nature that a deficient supply in food must be of rare occurrence; it is, however, often stated that an adult mammal living exclusively on a milk diet suffers from iron starvation.

When the body of an animal or a portion of such is subjected to heat strong enough to burn all the carbon compounds present, the metallic compounds are left behind, and form what is called the ash. The composition of the ash varies with the portion of the body thus tested; for instance, bone ash is chiefly calcium phosphate, muscle ash is chiefly potassium phosphate, and blood ash is chiefly sodium chloride. The percentage amount of ash in the whole body will vary with different species of animals, and will vary even with individuals of the same species. Generally speaking the fatter the animal the lower is the ash content. Thus, the ash of an

*Sulphates are also found to a slight extent in the blood, but they are probably waste products which the kidney is always endeavouring to remove.

ox will vary from 6—4.4 per cent., a sheep from 4—3 per cent., and a pig from 3—2 per cent.

The following table gives an idea of the percentage amount by weight of ash in different parts of the animal body:—

	Per cent.		Per cent.
Hair and brain	... 0.5—0.7	Cartilage ...	... 1.5—2
Blood ...	... 0.6—1	Bone ...	... 6—7
Muscle ...	... 1—1.5	Enamel of tooth	... 96—98

CARBOHYDRATES.

Carbohydrates are compounds of carbon, hydrogen, and oxygen, the last two elements being present in the same proportion as in water—hence the name. All carbohydrates can be burned in the presence of oxygen, and when thus treated yield two end-products of combustion, namely, water and carbon dioxide. The absence of nitrogen is always to be borne in mind.

It is usual to classify the carbohydrates into the following groups:—

Simple sugars, or MONOSACCHARIDES.
Compound sugars with two sugar components, or DISACCHARIDES.
Compound sugars with three sugar components, or TRISACCHARIDES.
Carbohydrates compounded of a large number of sugar components, or POLYSACCHARIDES.

MONOSACCHARIDES.—These bodies are all soluble in water, are sweet to the taste, and can be prepared in the form of white crystals. They not only burn when heated in the presence of air, but also combine with oxygen when in solution. This property is strikingly shown in the following simple experiment:—If to a few drops of copper sulphate (bluestone) solution some strong caustic potash is added, the colour gets slightly deeper and a faint flocculent precipitate of copper hydrate is formed. If a little glucose solution is added and the mixture be heated to boiling point, a copious red precipitate forms, due to the sugar robbing the copper hydrate of some of its oxygen. A large number of monosaccharides is known to the chemist, but only a few of them have any physiological importance; these few can now be taken in series.

1. DEXTROSE, called also GLUCOSE or GRAPE SUGAR. It is present, as the third name implies, in the juice of the grape. It is also found in the blood, in honey, in various vegetable juices, and in the urine of diabetic animals. It is prepared on a large scale by boiling starch with weak sulphuric acid. Dextrose ferments readily with yeast, producing alcohol and carbon dioxide.

2. LEVULOSE, called also FRUCTOSE or FRUIT SUGAR. This sugar is found associated with dextrose in honey and in many plant juices. It cannot be so readily crystallized as dextrose, and is much more difficult to prepare; in consequence it is a much more expensive article to purchase. Like dextrose, it ferments with yeast, producing alcohol and carbon dioxide.

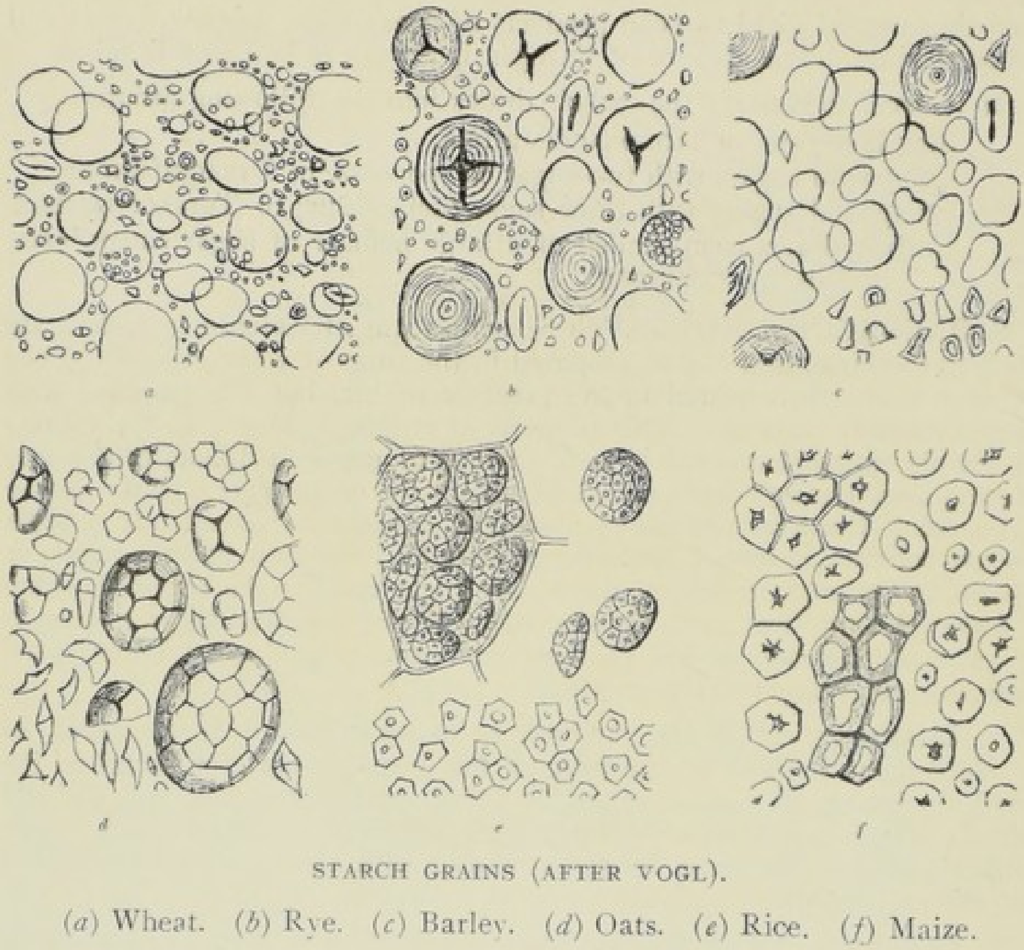
3. GALACTOSE, which is important on account of its relation to milk sugar, to be discussed later. With yeast it ferments either very slowly or not at all.

4. The PENTOSES.—This group comprises sugars which, though they are not found free in nature unless in exceptional circumstances, had better be mentioned here. They contain in their molecules less carbon, less hydrogen, and less oxygen than the three monosaccharides given above, and, in fact, belong to a different chemical category. None of them ferment with

yeast, and it is very doubtful whether they can be utilized to any great extent as food. In the human being, though they can be absorbed from the bowel, they pass through the body unchanged. ARABINOSE, prepared from gum arabic, and XYLOSE, prepared from wood, are the two pentoses best known.

DISACCHARIDES.—These compound sugars are, as has been stated, each composed of two simple sugars united chemically together. When boiled with acids they split up into their two components. Disaccharides are all white, crystalline, sweet to the taste, and soluble in water.

1. SACCHAROSE, called also CANE SUGAR or BEET SUGAR. This familiar sugar of commerce is found widely distributed in the vegetable world, as, for instance, in the nectar of flowers, in maize, in sorghum, but particularly



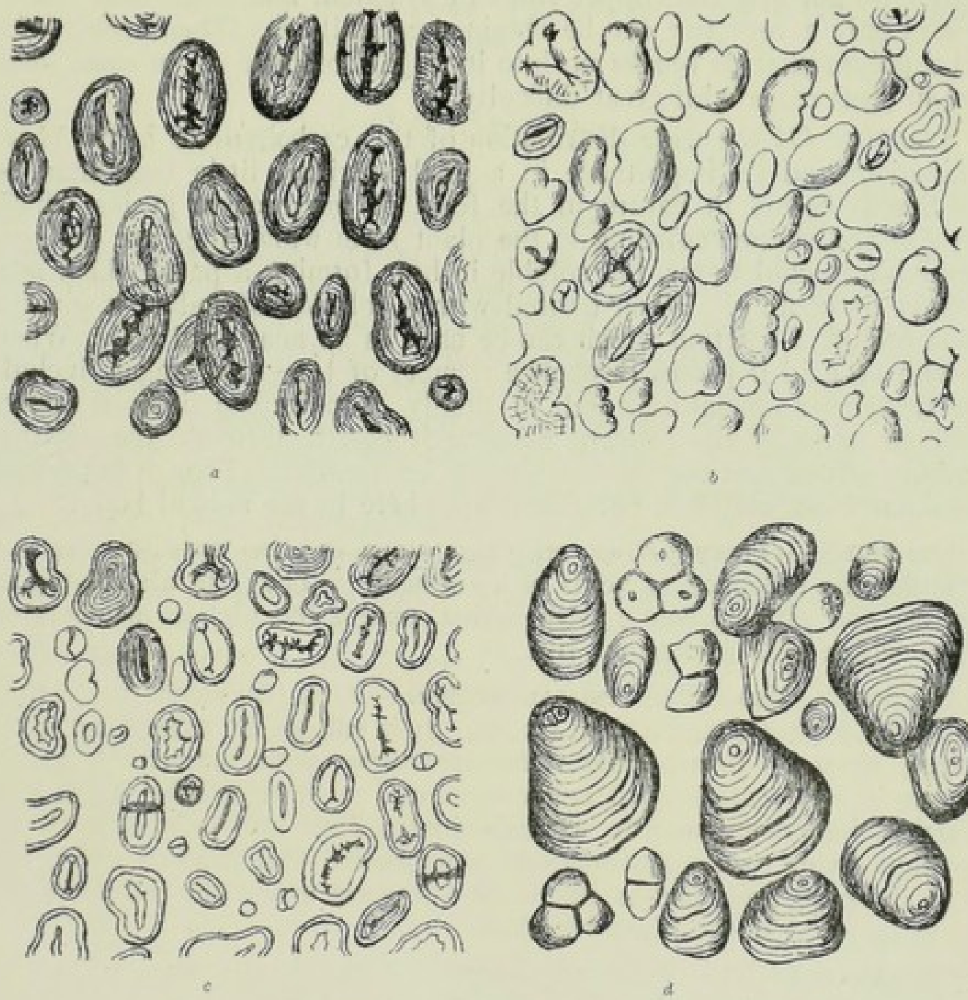
STARCH GRAINS (AFTER VOGL).

(*a*) Wheat. (*b*) Rye. (*c*) Barley. (*d*) Oats. (*e*) Rice. (*f*) Maize.

in the sugar cane and sugar beet. With yeast it ferments readily, but it does not give the copper sulphate test. When boiled with an acid it splits into its two components, namely, dextrose and levulose; this mixture is known as invert sugar, and is frequently used to adulterate honey which it closely resembles in chemical composition. Invert sugar gives, of course, the copper sulphate test as the two sugars, dextrose and levulose, are free and not combined chemically.

2. MALTOSE.—This disaccharide when boiled with an acid gives only dextrose, but it can be shown that each unit, or molecule, of maltose is composed of two dextrose units, or molecules, united together. It is found in germinating seeds, and thus is present in malt from which it derives its name. The malt extract of commerce is chiefly composed of a maltose

syrup. Maltose is a most important sugar from a bio-chemical stand-point, for into it all the starch of food must be changed by the action of digestive ferments before absorption by the bowel can take place. Maltose can be prepared in quantity by allowing seeds rich in starch to germinate or by subjecting starch itself to the action of the ferment diastase. Maltose, as is well known, ferments readily with yeast; it also gives the copper sulphate reaction.



STARCH GRAINS (AFTER VOGL)

(*a*) Bean. (*b*) Pea. (*c*) Lentil. (*d*) Potato.

3. LACTOSE, called also MILK SUGAR. This disaccharide, when boiled with an acid, splits into a mixture of dextrose and galactose. It gives the copper sulphate test, but ferments very slowly or not at all with ordinary yeast. It is not so sweet to the taste as the other disaccharides and is not so soluble. It is of importance in that it is the carbohydrate ingredient of milk, and is not produced anywhere in the animal kingdom except in the mammary gland (udder) of a mammal. It is readily attacked in solution by a bacillus (*bacillus lactis*) and transformed into lactic acid, a change which accounts for the souring of milk.

TRISACCHARIDES.—Only one trisaccharide is of importance, namely, RAFFINOSE, which is present in cotton seed, eucalyptus manna, and, to a small extent, in barley and beet. When boiled with an acid it gives rise to a mixture of dextrose, levulose and galactose.

A number of compound sugars with more than three components is known, but as these are of little bio-chemical importance we may pass to the carbohydrates with many components.

POLYSACCHARIDES.—These carbohydrates are each compounded of a large number of sugar components, how large it is as yet impossible to say. The polysaccharides differ markedly from the sugars of which they are composed; they are not sweet to the taste, they do not ferment with yeast, they do not give the copper sulphate reaction, many are insoluble in water, and only a very few can be obtained crystalline. When boiled with an acid a polysaccharide breaks up into its sugar components, in some cases readily, in some cases with great difficulty.

1. STARCH.—Of the wide distribution of this carbohydrate in the vegetable kingdom and its importance in animal nutrition little need here be said. Starch occurs in nature in the form of microscopic grains which vary in size and shape according to the plant from which they are derived. It is insoluble in cold water, but soluble in hot, forming a paste which sets into a jelly on cooling. When treated with a solution of iodine it gives a rich blue colour, a reaction which can be used as an analytical test. When boiled with an acid it passes through a number of transition stages, including the dextrins and maltose, and is finally transformed into dextrose. When acted upon by the ferment diastase it passes through the dextrin stages, but ends as maltose, as has already been noted. Though important as an animal food, starch is not found anywhere in the animal body.

2. DEXTRINS.—These bodies represent steps in the splitting up of starch under the influence of acids or a ferment. They are all soluble in cold water, and give no colour with iodine, except the highest members of the series which give a chestnut tint.

3. GLYCOGEN, also called ANIMAL STARCH.—This polysaccharide rather resembles the higher dextrins than starch. It is soluble in water, and gives an intense chestnut brown colour on treatment with iodine. Diastase transforms it into maltose, but acids can carry it further, like starch and the dextrins, into dextrose. It is found in the liver and in muscle tissue and in many living cells. It functions as a store of fuel food on which the body can draw at need, just as starch, and to some extent the celluloses act as reserve material in the plant kingdom.

4. CELLULOSE.—This substance makes up the greater part of wood, vegetable fibre, and the walls of vegetable cells. It is familiar in the form of cotton wool and filtering paper. It is insoluble in water, cold or hot, and is acted upon by dilute acids only in a very slow manner. Strong acids transform it into dextrose. In alkaline solutions it swells up and becomes semi-transparent. The property of being insoluble in water renders cellulose eminently fitted for the purpose to which it is put in nature, namely, to build up the greater part of the framework of the walls of vegetable cells, of vegetable fibres and of wood.

Its insolubility, however, makes it extremely difficult of digestion in the animal bowel; in some mammals it passes through practically unchanged, in others a small percentage is dissolved by the combined action of bacteria and a special ferment.

The HEMICELLULOSES differ from true cellulose in that they are not so resistant to solvents, and can be digested a little more readily; moreover, they also differ in their chemical composition, for, whilst cellulose proper yields only dextrose on treatment with acids, the hemicelluloses give rise to mixtures of various simple sugars. They are found in the outer covering of cereal seeds and in the reserve cellulose of plants.

The substance LIGNIN may be mentioned here. It is found in wood and in coarse woody fibre, and is a still more resistant substance than cellulose. Its chemical constitution has not been made out, and its chief physiological importance is that it passes through the animal bowel unchanged.

The cellulose group is quite unrepresented in mammalian tissues.

5. PENTOSANS.—These polysaccharides are compounded of pentoses, as treatment with an acid testifies. They are found chiefly in vegetable gums, but are also present in woody fibre. Pentosans are not found in the animal body, and their food value is very low.

FATS AND LIPOID.

Under the term fats we include not only ordinary animal fats but also the animal and vegetable oils, for these latter are simply fats that are liquid at ordinary temperatures. The term, however, does not include the mineral oils such as kerosene and paraffin oil, nor the "essential oils" of plants, which belong to totally different chemical classes and can neither act as foods nor take any part in forming the structures of the animal body. As common characters of fats which are well known we might mention that they are insoluble in water, and refuse to mix with it, and, as they are lighter weight for weight, they float on the surface of water. They boil at a temperature which is generally higher than the boiling-point of water, and they are readily inflammable.

Qualities not so generally known are the following: They are soluble in ether, chloroform and benzine. They are soluble in hot alcohol, but, as a rule, separate out in solid form on cooling. When liquid and when shaken with water containing even a small quantity of soap they break up into a multitude of droplets of microscopic size. These droplets, on account of their minuteness, rise to the surface so slowly that the fat may exist for a considerable time evenly distributed through the mixture—such a mixture being termed an *emulsion*. This formation of an emulsion in the presence of soap not only accounts for the detergent or cleansing action of this substance, but is, as we shall see, of the utmost importance in the digestion of fats.

Before we can understand the chemistry of fats mention must be made of the FATTY ACIDS. These acids contain carbon, hydrogen and oxygen, the carbon and hydrogen being greatly in excess of the oxygen. A large number are known to the chemist, and are classified in a regular series, the lower members of which (such as acetic acid) being liquid at ordinary temperatures and soluble in water, the higher members (such as stearic acid, present in certain candles and quite erroneously termed stearin) being solid at ordinary temperatures and insoluble in water. Between these extremes are intermediate forms, but the majority have solubilities like the fats; are, namely, insoluble in water but soluble in ether or hot alcohol. Many of the fatty acids possess a characteristic and often a very unpleasant smell.

Now, when a fatty acid forms a chemical compound with an *alkali* the result of the union is a *soap*; but when the fatty acid forms a chemical compound with *glycerine* the result is a *fat*. That fats are so compounded is shown by many facts and experiments. Fats, when subjected to the action of superheated steam, break up into glycerine and fatty acids; the same decomposition can occur through the action of bacteria or of a special ferment found in the mammalian bowel. When fats are boiled with an alkali, glycerine is produced, whilst the fatty acid unites with the alkali to form a soap.

Of the many fatty acids known to the chemist only some five need be mentioned here—

Stearic acid	which is	solid	at ordinary temperatures.
Palmitic acid	,,	solid	,, ,,
Oleic acid	,,	liquid	,, ,,
Caproic acid	,,	liquid	,, ,,
Butyric acid	,,	liquid	,, ,,

Now—	Stearic acid	united to	glycerine	gives the	fat stearin
	Palmitic acid	,,	,,	,,	,, palmitin
	Oleic acid	,,	,,	,,	,, olein
	Caproic acid	,,	,,	,,	,, caproin
	Butyric acid	,,	,,	,,	,, butyrin

Fats, as they occur in the body, contain always two or more of the fats above given, mixed together. Stearin and palmitin, when mixed, often go by the name of margarin, and the more of these two a fat contains the more solid will it be. On the other hand, olein, caproin and butyrin are liquids, and the larger the amount in which they are present the more fluid will be the fat. For instance, suet is chiefly composed of stearin and palmitin; olive oil contains olein as its chief ingredient, whilst milk fat or butter contains a considerable proportion of butyrin as well as some of the solid fats.

When a fat gets rancid what happens is that, through the agency of bacteria, the fat is split up into glycerine and fatty acid, the latter being readily detected by its odour—the smell of rancid butter, for instance, being due largely to butyric acid. In addition to this there is a slight oxidation of the liberated fatty acid and the consequent formation of other bodies which are not only odorous, but also harmful to the body when taken in food.

An interesting property of fats may be referred to here. When a liquid fat is shaken up with sodium carbonate it forms an emulsion exactly the same as if it had been shaken with soap. The reason for this is that in most fats there is always a small amount of free fatty acid which unites with the alkali in the sodium carbonate to form a soap, and it is this small amount of soap that conditions the emulsion.

Lipoid.—Lipoid is a substance found in the wall and in the protoplasm of every living animal cell, it forms the envelope of the red corpuscles of the blood, and also makes up the chief bulk of the myelin or insulating material of nerves. It possesses much the same solubilities as fats (soluble in ether, chloroform, and hot alcohol), but differs from them in this, that it can absorb water, and though not dissolving in the water, can mix with it. As a constituent of the cell wall, it carries out a most important function in controlling the permeability of the wall, allowing some bodies through more readily than others. Lipoid is composed of a variable mixture of at least two substances, lecithin and cholesterin. Lecithin is in reality a modified fat. Whilst fat contains carbon, hydrogen and oxygen, lecithin contains carbon, hydrogen, oxygen, nitrogen and phosphorus, and is in consequence often spoken of as a phosphorized fat. Lecithin can be prepared in considerable quantity from yolk of egg and from brain. Cholesterin.—With this body must be included the compounds it forms with fatty acids. Cholesterin can be prepared from brain, but the readiest source is wool-fat or lanoline. The compounds with fatty acids are much less readily broken up than fats, and, in consequence, do not become rancid so easily; hence the importance of lanoline as a basis for ointment, and hence the presence of cholesterin and its compounds in the natural ointment of most mammalian skins. Cholesterin is also found in the bile, and when, by any chance, it is no longer held in solution it forms a gall-stone or biliary calculus. Cholesterin is a compound of carbon, hydrogen and oxygen, but its exact chemical nature has not been fully made out.

CHAPTER V.

The Elements of Bio-Chemistry—(*Continued.*)

The Proteins.

We have seen in the preceding chapter that complex polysaccharides, such as starch, are formed by the union of many units of a comparatively simple sugar, namely dextrose. But the proteins with which this chapter deals are immensely more complex than any carbohydrate, for they are formed, not by the union of a number of units of a single substance, but by the union of many units of many substances. We have seen that a complex carbohydrate, when boiled with an acid, splits up into its component parts; the same occurs with a protein, and the chemist is able in this manner to determine what the constituent groups are. Now, the simple bodies into which proteins can be decomposed, and from which they can be built up by the plant or animal, all belong to the class of bodies called AMINO-ACIDS. These are soluble, crystalline substances, weakly acid in character, and containing nitrogen as well as carbon, hydrogen, and oxygen. It would be inadvisable here to give anything like a complete list of the amino-acids which can enter into the composition of proteins; the important ones only will be mentioned, and these are—

LEUCIN, which crystallizes in spherical lumps, and is gritty, like sand. It can often be seen as a sediment in pancreatic extracts,

GLYCOCOLL, which has a sweetish taste and is formed in quantity when gelatine is boiled with an acid,

TYROSIN, found in considerable amount in cheese, and hence its name (Greek, turos = cheese). This important amino-acid belongs to the same great class of chemical bodies as carbolic acid and benzoic acid, that is, the class of aromatic compounds,

TRYPTOPHANE, this body is the mother substance of nearly all the pigments of the animal body: in itself it possesses no colour, but when its structure is slightly modified it can yield substances of very rich tints—the colour of blood, bile, of urine, all being due to this body; even the green colouring matter in plants is a close ally. Moreover, it is largely to tryptophane that the evil smell of a putrid animal body is due, as also the smell of the fæces of carnivores, for tryptophane, under the action of bacteria, can pass readily into chemical bodies (indol, skatol, &c.), which have a penetrating and disgusting odour,

CYSTIN, this amino-acid contains not only carbon, hydrogen, oxygen, and nitrogen, but also sulphur, and it is to cystin that the sulphur content of protein is due. Cystin, when attacked by bacteria, gives off its sulphur as sulphuretted hydrogen, a poisonous gas which some people regard as having a most objectionable odour, and being reminiscent of rotten eggs,

HEXONE AMINO-ACIDS, these contain more nitrogen and have much weaker acidic properties than the amino-acids mentioned. They are present in all true proteins, and are obtained in considerable quantity from the soft roe of fishes.

This list, it must be remembered, is by no means complete, it omits many of the amino-acids (such as asparagin), but, as stated, it gives the important ones.

Now, if we imagine a large number of representatives of these amino-acids united to each other and forming an enormous molecule—a veritable tangle of amino-acid groups—we shall have something resembling a protein. The building up of a protein from its groups is performed rapidly and with ease by the animal or plant, but, so far, the chemist has not succeeded in performing this task in the laboratory.[1]

Proteins differ from each other, not only in the number of the groups present, but in the manner in which these components are arranged. There is practically an infinite variety of proteins possible, and we accordingly find a wide diversity between the proteins contained in living cells, of which they constitute the greater portion of the solid matter present.

Proteins in dry form are white and tasteless; a few can be prepared in crystalline form, for instance, the albumen of the white of egg, but only by very special treatment. Dry protein heated over a flame chars and gives off fumes that smell of burnt feathers; this smell, indeed, tells us that nitrogenous groups are present. The charring protein will readily take fire, and the char, which is chiefly carbon, will, if heated strongly enough, burn slowly away, leaving a very small residue of mineral ash. It is still a matter of debate how far these mineral salts enter into the composition of the protein; certainly no protein appears in the animal body that does not contain such salts, and the presence of the latter seems to be of vital importance; but, by suitable methods of washing, the amount of mineral matter may be reduced to a very small fraction of what was originally present.

A protein in solution tends to break up into a mixture of its amino-acid components. This is a very slow process, and can only be detected after the lapse of years, yet it is noticeable in tinned meats and preserved milk that have been stored a long time. This decomposition can be greatly accelerated, in fact, it can be completed in a few hours, by various means, one of which has been already stated, namely, boiling with an acid. A very interesting property of proteins, and one which has a very important practical as well as theoretical application is their inability to pass through a membrane composed of parchment paper or gelatine. If, for instance, we place white of egg in a bag made of parchment paper and dip this bag into pure water, the salts and sugars of the egg-white can diffuse into the water, but the protein remains behind as in a trap. If the water be renewed continuously, a time will come when nothing remains inside the bag but protein and water. This procedure is termed *dialysis*, and can be employed with a number of substances which, like protein, have large and highly complex molecules.

Proteins in solution can be thrown out as insoluble precipitates by means of various reagents. A number of these precipitations are frequently given as tests for proteins. Anything which precipitates protein destroys life if it gains access to the cell. The poisonous properties of corrosive sublimate, blue stone, sugar of lead, and most metallic salts are due to this fact, whilst a number of antiseptics owe their utility to their power of precipitating a part or all of the protein in bacteria.

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[1] It may be safely prophesied that this problem will shortly be solved by Dr. Emil Fischer, who appears to be within measurable reach of success.

Proteins can be precipitated by—

(*a*) Salts of heavy metals, for instance, mercuric chloride (corrosive sublimate), copper sulphate (blue stone), lead acetate (sugar of lead), iron chloride, &c.

(*b*) Strong mineral acids, notably nitric acid.

(*c*) Addition of ammonium sulphate to saturation point; the protein is here thrown out of solution in the same manner that soap is curdled by adding common salt to its solution.

(*d*) Certain reagents, like tannin or picric acid; the precipitation here produced depends upon the presence of the hexone amino-acids in the protein complex.

(*e*) Alcohol, which precipitates all proteins except a few occurring in the plant kingdom.

(*f*) To the above we might add the coagulation produced by boiling; the number of proteins thus precipitated is small, but the two chief animal proteins (albumens and globulins) possess this character.

In addition to these precipitation re-actions, proteins yield a number of colour tests when treated with certain re-agents—

(*a*) Due to the presence of tyrosin.—When protein is warmed with nitric acid, a yellow colour is produced; if the mixture is then cooled and ammonia added, an orange tint is developed. This reaction is frequently observed with young chemists who spill nitric acid over their fingers, a yellow stain is formed, which darkens with ammonia.

(*b*) Due to the presence of tryptophane.—If to a solution of protein a small quantity of strong acetic acid (which has been kept some time) is added, and then large excess of strong sulphuric acid, a splendid purple colour is produced.

(*c*) Due to the presence of cystin.—If protein, strong potash, and lead acetate be boiled together, the mixture darkens owing to the formation of sulphide of lead. The darkening of a silver egg-spoon is similarly due to the formation of silver sulphide, the sulphur being derived from the cystin of the albumen.

(*d*) Due to the manner in which the amino-acids are linked together.—If to protein solution some strong potash is added, and then a few drops of weak copper sulphate solution, a pretty violet-pink colour is produced; this colour can be readily distinguished from the bluish shade which would be formed if the protein were absent.

The percentage composition of dry protein deprived of mineral matter is generally given as follows:—

Carbon	50.6 — 54.5	per cent.
Hydrogen	6.5 — 7.3	per cent.
Nitrogen	15.0 — 17.6	per cent.
Sulphur	0.3 — 2.2	per cent.
Oxygen	21.50 — 23.50	per cent.

It will be seen that carbon constitutes more than one-half, and nitrogen about a sixth of the whole.

Classification of Proteins.

ALBUMENS.—Albumens are present in blood, milk, eggs, seeds, and bioplasm generally. The albumens differ but slightly from one another, and are named according to their origin. Thus, LACTALBUMEN is found in milk (but in small quantity compared with its chief protein caseinogen), SERUM ALBUMEN in blood, whilst EGG ALBUMEN or OVALBUMEN constitutes the chief solid constituent of white of egg. Albumens are soluble in water, and are coagulated by heat as is familiar to us in the cooking of an egg.

GLOBULINS.—Globulins accompany albumens wherever these are found. The chief protein in muscle is a globulin, and the more important vegetable proteins belong also to this class. Globulins, like albumens, are coagulated by heat, witness the cooking of meat, but, unlike albumens, are insoluble in pure water. The addition of a small amount of salt to the water renders them soluble, and in this way they can appear in bioplasm, blood, &c., in dissolved form.

PHOSPHO-PROTEINS.—These are more complex than the two preceding, and, as the name implies, are rich in phosphorus. The most important phospho-protein is CASEINOGEN,[1] the chief protein in milk. Caseinogen is insoluble in water and dilute acids, but soluble in weak alkalies. If to a solution in weak alkali sufficient acid be added, the caseinogen is thrown out as a precipitate. This explains the curdling of milk when it sours or when acid is deliberately added to it.[2] Caseinogen in solution is not coagulated by boiling.

Another important phospho-protein is VITELLIN, which is found in yolk of egg.

NUCLEO-PROTEINS.—These are present in large amount in the nuclei, and, to a lesser extent, in protoplasm; they are also found in certain body-fluids, particularly in the bile of the ox.

The structure of the nucleo-proteins is extremely complex, as no less than two complete protein molecules are linked on to a complex acid called nucleic acid. This nucleic acid is itself fairly complex in structure, and, though not comparable with protein, has nevertheless several groups of bodies present, amongst which we may note a sugar, phosphoric acid, and some compounds of carbon, hydrogen, oxygen, and nitrogen, which are closely allied to uric acid. Nucleic acid united with one protein group gives NUCLEIN, with two protein groups, NUCLEO-PROTEIN.

The nucleo-proteins have many properties in common with caseinogen, for example, they are not coagulated by heat, are insoluble in water and weak acids, but soluble in weak alkalies.

GLUCOPROTEINS.—These are compounded of protein and a carbohydrate. The chief glucoprotein is MUCIN, the glairy adhesive material which is found in the inner wall of most canals and ducts of the body. It is present also in large quantity in the slime of snails and in the saliva of most mammals. If to saliva we add some dilute acid, the mucin is thrown out as a stringy precipitate, which can be redissolved by adding sufficient alkali. The solubilities of mucin are the same as those of caseinogen and nucleo-proteins.

CHROMOPROTEINS.—The chief chromoprotein is HÆMOGLOBIN, which is a compound of protein and a substance called hæmatin. This

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[1] An unfortunate confusion exists as to the nomenclature of this protein. In England the term caseinogen is used for the chief protein of milk, and casein is restricted to the product of rennin clotting; in Germany, kasein is used for the former and parakasein for the latter. The Americans and some English chemists follow the German nomenclature. In accordance with the views of the committee appointed jointly by the Chemical and Physiological Societies of England the term CASEIN is used for the rennin product and CASEINOGEN for the unaltered protein as it occurs in milk.

[2] The reader must bear in mind the fundamental difference between the clotting of milk by an acid and the clotting produced by ferments, such as rennin. In the former case, the caseinogen is rendered insoluble by the acid, but is not chemically altered and can be brought back again into the soluble form. With rennin a distinct chemical transformation occurs, and the product casein cannot by any means be made to revert to caseinogen.

hæmatin contains iron, is rich in derivatives of tryptophane, and is red in colour. We find hæmoglobin in the red corpuscles of the blood, and constituting about 30 per cent. of their weight.

METAPROTEINS.—When proteins are treated with dilute acid or alkali in the cold, products called ACID-ALBUMEN and ALKALI-ALBUMEN respectively are formed. These are soluble in the acid or alkali employed, and do not coagulate on heating. If, for instance, a piece of meat is placed in dilute hydrochloric acid, a considerable part of the protein is dissolved out as acid-albumen; this acid extract can be boiled without formation of a coagulum, but, if it be neutralized with alkali, a curdy precipitate at once forms. If alkali be employed to extract the meat, the solution is rapid.

PROTEOSES, PEPTONES, and POLYPEPTIDES.—When protein undergoes disintegration into its component amino-acids, a number of steps can be traced by the loss of one true protein property after another. When coagulation by heat is lost, and when copper sulphate and potash give a rose-pink instead of a violet, the product consists of a mixture of PROTEOSES. When, in a further stage of disintegration, the property of being precipitated by ammonium sulphate is lost, and the substance can penetrate through parchment paper, the product is termed PEPTONE.[1] Below the peptones come the POLYPEPTIDES, which no longer give any distinctive colour with copper sulphate and potash, and finally the amino-acids themselves.

SCLERO-PROTEINS (called by some authors ALBUMINOIDS).—These are compounded of amino-acids, but, unlike the previously-mentioned proteins, contain little or no tyrosin or tryptophane. They are all insoluble in cold water, and are fairly resistant to chemical reagents. They cannot be substituted for protein in food, and are used in the body, as constituents of connective tissue, horn, hoof, &c., on account of their physical properties.

1. KERATIN, the basis of hair, feathers, horn, and the outer layers of the skin. It is very tenacious and resistant to chemical attacks. It contains more cystin, and, therefore, more sulphur, than ordinary protein.

2. COLLAGEN, generally present in the form of fine fibres or sheets which make up the greater part of connective tissues (see Chapter II.). Collagen is a colourless inelastic substance, insoluble in water, and of remarkable tenacity. When boiled with water, or treated with dilute acids, it swells up and changes into gelatine.

3. CHONDROGEN, closely allied to collagen, and forming the basis of cartilage (gristle).

4. ELASTIN, also closely allied to collagen, but differing in its physical properties. It is a highly elastic substance in the sense that indiarubber is elastic, and forms the basis of elastic fibres, such as are found in the *ligamentum nuchæ*, etc.

VEGETABLE PROTEINS.—These, which occur widely distributed throughout all plants, and which are of special importance in connexion with the question of fodders, are partly globulins, partly albumens, and partly proteins which cannot well be classified. Some of them possess the remarkable property of being soluble in alcohol. Generally speaking, they are insoluble in water, and require much more salt for their solution than do the animal globulins.

[1] The article on the market called Witte's Peptone contains very little true peptone; it is chiefly a mixture of proteoses.

CHAPTER VI.

The Elements of Bio-Chemistry—(*Continued.*)

The Enzymes.

The changes denoted by the word fermentation have long been a mystery to the human mind. The most familiar example of this process is the transformation of sugar into alcohol and a gas (carbon di-oxide) by the action of yeast. The salient feature in all fermentations is the large amount of substance which is changed by a small amount of ferment without any loss of power being incurred by the ferment. To explain this mystery many crude theories have been put forward from time to time such as the philosophers' stone, spiritual agency, &c. The great Liebig fell into the blunder of regarding it as a simple chemical transformation unconnected in any way with life. It was the brilliant work of Pasteur that proved conclusively that yeast was a living thing—a plant in fact. He showed that putrefaction was caused by living bacteria and that the souring of milk and kindred changes were due to living things. Before Pasteur's discovery a few observations had been made on certain products of living things, but themselves not living, which could produce changes allied to fermentation. Thus, in the saliva, a ferment was discovered which, though present in minute amounts, could transform large quantities of starch into sugar. In the gastric juice a ferment pepsin was found which, in conjunction with an acid, could digest protein. Independently of these workers the chemists had discovered a number of reactions in which small amounts of substance could produce changes in immensely greater quantities of other substances without themselves undergoing any change. Thus it was found that hydrogen and oxygen would unite almost instantaneously in the presence of a minute amount of platinum, the platinum remaining unaffected and capable of producing the same change apparently for all time. To such reactions the name *contact reactions* was given and later the name *catalysis*. The number of catalytic reactions known to the modern chemist is very great and catalysis is being more and more employed in the laboratory and manufactory. But the mere naming of a reaction did not do away with the mystery. A step in the solution of this problem was made when it was shown that in all catalytic reactions the essential feature is a hastening, an *acceleration* of a change which is normally going on but in a very slow manner. Hydrogen and oxygen mixed in a test-tube at ordinary temperatures are really uniting to form water, but the change is so slow that the life time of a man would be insufficient to show any appreciable diminution in bulk; introduce a tiny speck of spongy platinum and the reaction is over in a fraction of a second. Hydrogen peroxide is continuously decomposing into oxygen and water but at a slow rate; introduce a drop of water in which finely divided platinum is floating and the decomposition gains enormously in rate even though the amount of platinum added can only be expressed in millionths of a grain.

If pure copper be dipped into pure nitric acid no reaction is at first observed, but introduce an unweighably small amount of sodium nitrite and the copper is immediately attacked by the acid. Catalytic reactions are checked by cold and increased by heat and show a marked sensitiveness to the presence of certain other bodies for which the term *poisons* has been borrowed from medical science. Thus a minute amount of prussic acid will stop the catalytic action of platinum on hydrogen peroxide and mere traces of arsenic will hinder the catalytic action of the same metal as it is employed in the manufacture of sulphuric acid.

Now this idea can be extended to the ferments of saliva and gastric juice. The action of the diastase of saliva or of malt extract is simply an acceleration of the change from starch into sugar which is normally progressing at a very slow rate. The same may be said of pepsin. It has been noted in the previous chapter that proteins tend to disintegrate even when sheltered from bacteria, but that some years must elapse before this is noticeable. Now all that pepsin does is to bring about in an hour or two what might otherwise take a full century to accomplish. Neither the diastase nor the pepsin does any actual work; their action may be compared with oiling the axles or removing the brake from a truck which is slowly crawling downhill. To catalysors such as diastase and pepsin, which are products of life but not themselves living, the term ENZYMES has been given.

But what of the fermentations like the alcoholic which apparently demand the existence of life in their midst? In 1895 a discovery was made that yeast may be killed and an extract made from it which can carry out the alcoholic fermentation in a rapid manner. It had already been shown that sugar solution placed in sunlight shows traces of alcohol after a lapse of a considerable time. Clearly the yeast when it transforms sugar into alcohol does so by means of an enzyme which accelerates a process already in action. Kindred discoveries were made with various bacteria and with living organs so that we can now state that a large number of the reactions carried out in the animal body are due to enzymes, which enzymes are specially made by living cells for those particular reactions.

When we consider the immense number of chemical substances which are made or transformed by living things we cannot but be amazed at the ease with which these activities are conducted and in the face of so many difficulties. A chemist in his laboratory can employ high and low temperatures, high and low pressures, he may use strong acids and alkalies, he may crystallise, volatilise and sublime, yet even in the mammalian body, highly as it is organised, all reactions proceed within a temperature range of a few degrees, pressure is everywhere constant, the reaction is neutral or only very faintly acid or alkaline, crystallization, at least in animals, is never resorted to, and volatilisation and sublimation are impossible. Despite this heavy handicap the body can produce, rapidly, accurately and economically, a host of chemical compounds which defy the utmost resources of the chemist even to analyse. As research in physiology has proceeded it has been found that many chemical reactions which were formerly thought to be due to mysterious powers of life can be classified as catalytic. The mysterious part remains in the fact that the cell makes anew the proper catalysor at the proper time and in the proper place. This is but another response to change in environment.

Single-celled animals have but a small equipment of enzymes to liberate, as compared with higher animals where special sets of catalysors are relegated to special organs and the total number thus made very great.

Some special characters of enzymes may now be described in detail.

1. Enzymes are probably closely related to proteins in constitution. Chemical reagents which precipitate proteins destroy enzymes. They are, like albumens and globulins, altered by heat, in fact no enzyme in solution can stand a temperature of 70°C. and many not even 60°C. Thus it happens that an enzyme has an optimum temperature, *i.e.*, a temperature at which it acts most rapidly. If the temperature be increased from zero upwards the activity of the enzyme increases too, but when the heat becomes sufficiently great to injure the enzyme its activity begins to fall off and will eventually disappear. With the majority of enzymes the optimum temperature is just a little above the temperature of the mammalian body. Unfortunately no enzyme has ever been isolated in a pure form, in fact we have no idea, when we have a solution of an enzyme, how much of the solid matter present is impurity and how much is ferment.

2. Enzymes act specifically. An acid, as we have seen, can split up all disaccharides, all polysaccharides and all proteins, but such universal application in an enzyme would be disastrous to the bioplasm. We find for instance that the enzyme which accelerates the splitting of cane sugar into dextrose and levulose, fails utterly to act on any other disaccharide, not to mention polysaccharides and proteins. It is highly probable that each enzyme unites at first with the body acted on and has a structure related in some way to the structure of the latter as the wards of a key are related to the lock. We find many instances of an enzyme acting not on one but on a small number of bodies, yet when these are investigated it will be found that they all present some striking similarity in chemical structure. Thus the alcohol-producing ferment of yeast or *zymase*, as it is called, can act not only on dextrose but on levulose and another sugar called mannose.

3. Enzymes determine the direction of change. One enzyme will transform dextrose into alcohol and carbon dioxide, another will change it into butyric acid and hydrogen, a third will transform it into lactic acid. Here we have a quality which seems at variance with the law concerning the accelerating action of enzymes. This point has not yet been properly investigated, but the probable solution of the difficulty seems to be that dextrose of itself tends to decompose into carbon dioxide and water, whilst alcohol, butyric acid and lactic acid are all steps towards this end. This brings us to the next property.

4. Enzymes, much more than inorganic catalysors, tend to halt at some stage of change. An acid will carry starch through dextrins and maltose into dextrose, but the enzyme which acts on starch (*diastase*) will carry the change as far as maltose and then stop.

5. Enzymes like catalysors generally may be poisoned by minute quantities of other substances. Prussic acid even in minute doses stops the action of all enzymes and to this its great poisonous action in the body is due.

6. Enzymes, like other catalysors, may be the cause of extensive changes though present in very minute amounts. Owing to the reason already given the amount of an enzyme in solution cannot be determined but even granting that all the solid matter were enzyme the amount of change which it can produce is surprising. Thus one part by weight of rennin can transform 100,000 times its weight of caseinogen into casein.

7. As enzymes accelerate changes, which normally occur but slowly, it can be shown that all these changes are from a condition of a higher

to a lower potential energy. The enzyme does not put work into the system that it acts on; on the contrary it liberates available energy and allows work to be done. The transformation of sugar into alcohol and carbon dioxide is accompanied by the formation of heat; we may liken the sugar to a reservoir of water on a hill side and the action of the enzyme *zymase* to the opening of a tap which allows the water to run down into another reservoir at a lower level. The action of an oxidising enzyme which transforms alcohol into water and carbon dioxide we can further liken to a second tap which allows the water in this lower reservoir to rush down to the sea.

Enzymes are found wherever there is living bioplasm and without enzymes life is impossible. In most cases, if not all, a number of enzymes working instantaneously or in succession may be observed. Thus the yeast plant, if placed in a cane sugar solution, can make no use of its zymase unless the cane sugar is first of all split up by another enzyme called *invertase*. In the same manner the yeast plant produces *maltase* which transforms maltose into dextrose and allows the zymase scope for its activity. But most of the yeasts employed have no enzyme which can accelerate a change of lactose into dextrose and galactose and hence in a solution of this sugar no alcohol may be produced.

In many cases we can show that the free enzyme does not exist as such in the cell; it is present in an inactive form, a mother substance or *pro-enzyme* which we may liken to a knife in a sheath or a gun at half cock. Probably this is the case with all enzymes.

We see that living bioplasm does not merely store bodies at high potential energy and let them degrade into bodies of low potential energy; it can accelerate this degradation and for all we know may be able to check it at the right time and in the required direction. To make a very rough analogy the molecules of food may be likened to a number of wound-up watch-springs, whilst the cell is composed of a number of complicated clockwork mechanisms. The cell then places each spring in the proper machine and sets it going or checks its action when changes in the environment induce it to do so. Only a limited number of springs can be employed, namely those that fit the various mechanisms.

We find enzymes not only in the food canal where they are of service in digesting food; in the tissues for the liberation of energy, the getting rid of waste and the formation of new compounds; but also in every living cell where they have the power of digesting and destroying the cell should the latter be cut off from the circulation. If an organ, say the liver, the spleen or a piece of muscle, be cut out of a living animal or one recently dead, it will begin to disintegrate and its proteins be changed into amino-acids even though bacteria be rigidly excluded. This process has been termed *autolysis* or self digestion. If the organ were heated to boiling point then no autolysis would occur and the proteins present would remain intact for many years. Autolysis explains the softening of meat when it is hung and is of immense importance in the digestion of food by horses and ruminants. We see autolysis also in an organ which remains in its normal condition but from which the blood supply has been cut off. The probable reason for this strange occurrence is that during starvation the body has to live on itself, that is, has to digest its own substance as food, and that cutting an organ away from the circulation is only an extreme form of starvation.

CLASSIFICATION OF THE MORE IMPORTANT ENZYMES FOUND IN THE ANIMAL BODY.

a. Those that act on carbohydrates—

- INVERTASE which changes cane-sugar into dextrose and levulose.
- MALTASE which changes maltose into dextrose.
- LACTASE which changes lactose into dextrose and galactose.
- DIASTASE which changes starch, glycogen and dextrin into maltose.

b. Those acting on proteins—

- TRYPSIN which changes protein into amino acids.
- PEPSIN (in conjunction with an acid) which changes protein into proteoses.
- EREPSIN which changes proteoses into amino acids.

c. Those acting on fats—

- LIPASE which changes fats into glycerine and fatty acids.

d. Those which accelerate the oxidation of substances—

- OXIDASES, probably many in number, and each fitted for the oxidation of a particular substance.

e. Those which produce clotting—

- THROMBIN (called also FIBRIN-FERMENT) which changes soluble fibrinogen in the blood into the clot fibrin.
- RENNIN (called also LAB) which transforms soluble caseinogen into the curd casein.

CHAPTER VII.

Muscle.

Muscle we may regard as the tissue which is responsible for all intrinsic movements in the higher animals whether of the body as a whole (running, swimming, jumping, &c.) or of individual parts of the body (circulation of the blood, movements of eyes jaws stomach &c.). As has been already stated, the essential elements of muscle are cells in which contractility is highly specialised. All muscle-cells are longer than they are broad and when they contract the length is diminished whilst the breadth is increased. The change is therefore one of shape and not of size.

Skeletal Muscle.

The subdivision of muscle into three classes has already been given. The first class which is called *striped*, *voluntary* or *skeletal* muscle, and which is familiar to us as the flesh of an animal, possesses certain characters already implied in these names. Such muscle on microscopic examination is seen to consist of cells which are striped horizontally, the stripes being due to rows of little prismatic bodies which by their change of shape determine the total change of shape in the cell. The second name implies that they are under the control of the will. They are set into activity solely by nerve impulses which come to them from the central nervous system and are more dependent on the central nervous system than any other form of tissue, for, if the nerve supplying the muscle be cut and not allowed to heal, the muscle rapidly undergoes atrophy and dies. The third name informs us that such muscles are attached, at least by one end, to bone and by their contraction can, in most cases, make certain bones to move with respect to each other. A glance at the illustration on page 344 will make this clear. Here two muscles are shown, the *tibialis anticus* and the *gastrocnemius*, which have each a double bony attachment. In each of these types there is a broad origin and a narrow insertion by means of a tendon or sinew, but these features are by no means universal amongst muscles. Now if the gastrocnemius alone were to contract, the calcaneum would be drawn nearer to the femur, in other words the hock would be opened out or extended, and the stifle somewhat flexed. If the tibialis anticus alone were to contract, the hock would be flexed. With respect to the hock these two muscles are therefore antagonistic in their action and similar arrangements will be found if we examine any other joint, one set of muscles being extensor and the other flexor. The necessity of such an arrangement is obvious, for a muscle, whilst it can pull cannot push, and furthermore delicate and skilled movement of a limb can be best brought about by having both sets contracted and allowing one set to act a little more powerfully than the other. In ball and socket joints such as the hip, shoulder and eye we find sets of muscles on four or more aspects so that the range of movement may be increased.

Nature of muscle contraction.—A muscle is in reality an engine for transforming energy into work. Each muscle is continually drawing on the blood with which it is copiously perfused for a supply of nitrogen-free carbon compounds with a relatively high potential energy. When the muscle contracts these compounds are broken down and energy is liberated. A sufficient supply of oxygen is also essential. It was formerly thought that these carbon compounds were burned by the oxygen with the formation of heat and that the heat thus produced made the prisms in the muscle cell contract, just as stretched catgut will contract when its temperature is raised. But muscle works far too economically for this to be the case. More probably the carbon compounds, by a partial disintegration, give rise to electric energy which is transformed

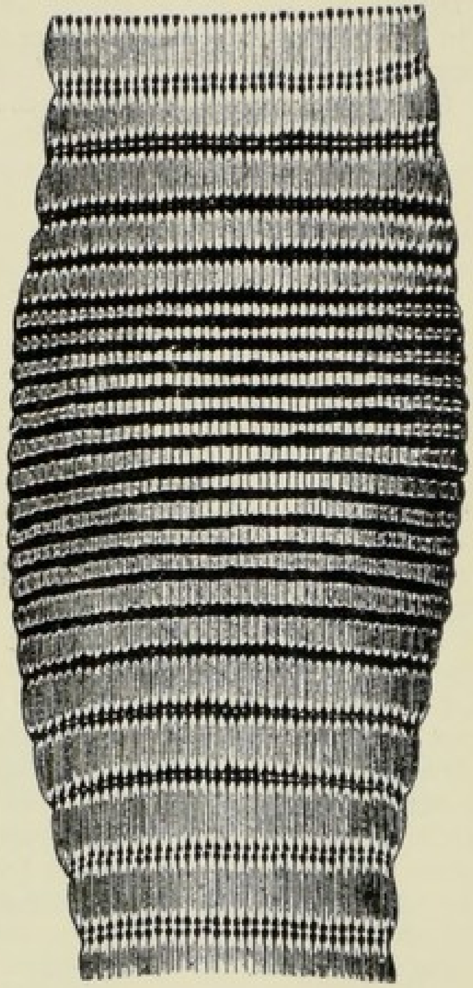

Fig. 40.—Part of a contractile cell of skeletal muscle. The cross stripes are due to the rows of prismatic bodies. A wave of contraction is seen passing along the cell. (After Schäfer.)

into work; then these break down products, which if allowed to accumulate would check the production of electric energy, are burnt up by the oxygen. Whatever be the exact nature of the transformation, we know that the final chemical products of muscular activity are water and carbonic acid. If oxygen be withheld from the muscle the latter can go on contracting for some time but weaker and weaker until it eventually ceases to respond to even the most urgent nerve impulses. If we examine a muscle in this condition we shall find that it is acid in reaction, and that this acidity is due to the presence of lactic acid which possibly represents one of the break down products which normally are burnt off.

The carbon compounds which bring potential energy to muscle can be derived from either carbohydrates, proteins or fats. In the case of proteins the nitrogenous parts of the molecule are previously split off, forming urea which leaves the body by the kidney, whilst the more carbonaceous part can be used as a muscle fuel-food. There is some evidence to show that the carbon compounds derived from proteins can yield their energy to muscle at a quicker rate than those derived from carbohydrate and fats. An ox, for instance, whose diet is largely carbohydrate, may do far more work in a day than a tiger, but such work is performed in a comparatively slow and regular manner. The tiger, as a protein-eater, can command a sudden liberation of energy in its muscles and can in consequence drag the ox down, kill it, and run off with it. The same thing is shown in horses which are put on a liberal protein ration; they become spirited and fresh and are better able to produce the swift and powerful muscular contractions that are needed in a race.

It has been stated that a muscle as an engine works economically. Speaking generally a muscle can transform 30 per cent. of the energy it receives into work, the remaining 70 per cent. taking the form of heat which warms the muscle and escapes into the blood and surrounding tissues. Another way of stating this fact is to say that muscles supplied with a certain amount of carbonaceous matter will produce only 70 per cent. of the heat which these same compounds would give rise to if burned elsewhere. Now this 30 per cent. efficiency of a muscle places it far above any steam engine as an economical machine. It is not however so economical as some of the latest forms of oil engines which have an efficiency of close on 40 per cent.

From the foregoing facts we can now state that, when a muscle contracts, it uses up nitrogen-free carbon compounds and oxygen, gives off water and carbonic acid, and produces heat.

Factors that influence muscular contraction.—Even though a muscle may not be contracting visibly we shall find that in a conscious animal it is shorter than if the animal were narcotised or asleep. This slight, but constant, contraction, which keeps the muscle taut and ready at a moment's notice to contract forcibly in response to a stronger nerve message, is called "muscle tone."

The greater the resistance to be overcome the greater is the force of contraction. This can be seen even in a muscle which has been cut out of a recently killed animal; within certain limits it liberates more energy and contracts more forcibly, the more it is hampered in its contraction. Then again we are aware that by our will we can make a muscle act strongly or weakly as we are inclined. That is to say, the force of a muscular contraction will vary according to the nerve message the muscle receives.

It is an every day experience to find that exercise increases muscular power. This is due to two factors. First, the exercise itself actually makes the muscle either bigger or more efficient; and secondly, when an exercise is repeated and learnt, unnecessary muscular exertion is avoided. When an animal performs a skilled action for the first time (a man doing an athletic exercise, or a horse jumping or in harness) a number of superfluous muscles are called into play and antagonistic muscles are too forcibly contracted. When the exercise is learnt the requisite muscles and no more, receive the nerve messages calling on them to contract, and hence the work is done more economically and with less fatigue. When a muscle, acting under the influence of the will, and opposed by a resistance sufficiently great, continues contracting until fatigue has set in and the resistance can no longer be overcome, we find that the contractile substance of the muscle is still capable of doing vigorous work. If for instance a weight be lifted by the flexion of a single finger until utter fatigue has set in, and the muscle, or its nerve, be stimulated in the arm by an electric shock, the weight will be lifted, and can continue to be lifted, for a considerable time. Fatigue, in fact, is most strongly marked in the motor nerve-cells of the central nervous system, much less strongly marked in the receptive substance of the muscle, and still less in the contractile mechanism of the muscle; for a muscle if stimulated directly can contract long after it has ceased to contract on stimulation of its nerve.

That muscular power is different in different individuals; is less in the female than in the male; and is greater in adult life than in youth

Fig. 41.—The muscle on the right is the gastrocnemius, that on the left is the tibialis anticus. (After Hagemann.).

or old age, is well known. These differences are due, partly to the differences in number and size of the muscle cells, and partly to the variable efficiency of the contractile elements.

Chemical composition of muscle.—The contractile cells of muscle are arranged on a scaffolding of fibrous connective tissue. Moreover connective tissue sheets pass through and through the muscle marking off the muscle cells into bundles. With the connective tissue there is always some fat. As the amounts of connective tissue and fat are very inconstant, the chemical composition of muscle substance varies within wide limits. As an average of the figures obtained for muscle which has been freed from fat as far as the eye could determine we may take the following as useful:—

	Per Cent.
Water	75
Proteins	18
Chondrogen and fat	2·5
Mineral matter	1·2
Glycogen and various extractives* ...	0·9

We have seen that muscle requires carbon compounds as sources of energy, but it also requires true protein for repair. A muscle, like any other machine, is constantly losing some of its substance from wear and tear, but this (unlike the machine) is constantly being replaced from the proteins of the blood. This amount of repair protein is very small as compared with the amount of carbon compounds used as energy supply.

Death of muscle.—When an animal dies and the circulation stops, the muscles continue to live for some time, as is shown by their contracting on stimulation by electricity; but as no oxygen is brought to them the breakdown products, including lactic acid, accumulate and make the reaction markedly acid. When these substances have been heaped up to a certain degree, part of the protein of the muscle coagulates and this coagulation produces a shortening of the muscle so that all the limbs of the dead body become for a time quite rigid. This death stiffening is termed *rigor mortis*. We may summarise the condition of a muscle in rigor mortis by stating that it is more opaque than normal, is acid in reaction, is in a contracted condition due to coagulation of certain proteins, and is no longer responsive in any way to stimulation—in other words is dead. Then autolysis or self digestion sets in, the rigidity disappears, and, in the case of an animal killed for food, the flesh becomes more tender. Bacteria of course find autolysed muscle a suitable habitat and will complete the breakdown, aided by the larvæ of various insects, if the muscle (meat) be left exposed to the air.

Heart Muscle.

Heart muscle differs from skeletal chiefly in the fact that its contrations are rhythmic in character, are short and quick, and further, that they do not depend for their existence on the central nervous system. As we shall see later, the nerve impulses that pass to the heart from the central nervous system, only modify the rate or force of the contraction; if the nerves are cut, the heart continues to beat and, unlike skeletal muscle, shows no sign of atrophy. Whether this power of beating rhythmically is a property of heart muscle or is due to a nervous mechanism embedded in the heart substance, is still a debatable point. The heart resembles skeletal muscle in using nitrogen-free carbon compounds as sources of energy and in requiring a liberal supply of oxygen; it also contracts more forcibly the greater the resistance it encounters and it passes into rigor mortis in much the same manner. It is unlike skeletal muscle in being less dependent on the central nervous system, in not being under the control of the will and in the much more restricted range in the variation of its force.

*By the term extractives is meant those simple chemical substances which make up the main part of meat extract.

Involuntary or Smooth Muscle.

Smooth muscle is peculiar in that it can remain almost indefinitely in a tonic state of contraction without displaying fatigue. This state of contraction is subject to rhythmic alterations. Both tonic contraction and rhythmic change can exist if all connection with the central nervous system is cut off; they are conditioned by an intrinsic nervous mechanism or are actual properties of the muscle itself. Nerve impulses passing into smooth muscle from the central nervous system can increase or diminish the force of the contraction. These properties of smooth muscle make it of service in the walls of arteries and veins and in hollow viscera like the stomach, gut and uterus, &c., where sustained contraction is essential. It is also found in the iris, constricting or dilating the pupil; within the eyeball and concerned with the focussing of the lens; and in the skin producing ruffling of hair, fur or feathers. As one of its names implies, it is not under the control of the will, but like the heart receives nerve impulses *viâ* the autonomic system.

CHAPTER VIII.

Animal Heat.

It has long been recognised that from the stand-point alone of temperature animals can be divided into two great groups. The popular terms for these groups namely *cold-blooded* and *warm-blooded* are based upon very profound differences, but they are not too well chosen, for a so-called cold-blooded animal, say, a snake, may occasionally have a temperature exceeding that of a so-called warm-blooded animal, say a man or a horse. The true distinguishing point is this that, in one class, the temperature of the animal is never far removed from the temperature of the environment, and that it varies within wide limits and parallel with the changes in temperature to which the animal is exposed. The temperature of such an animal is in fact determined by the temperature of the environment in which it lives. Such an animal we may call an animal of variable temperature or, to use the technical adjective, a *poikilothermal* animal. But when we examine a bird or a mammal we find that its temperature varies within extremely narrow limits, is independent of ordinary changes in environment and has a marked tendency to remain constant. Birds and mammals are therefore constant-temperature animals or *homoiothermal*. The homoiothermal animals by virtue of their constant temperature possess many advantages over the poikilothermal. It has already been stated that the activities of all cells increase or decrease as the temperature of the cells rises or falls. Thus it is that a lizard is active on a warm day but sluggish on a cold one. The vitality of such a creature is constantly changing with the weather and the animal has but feeble powers of resisting extremes of temperature. A homoiothermal animal on the other hand can remain uniformly active despite extensive changes in climate or season and is not compelled on the onset of cold to abate one jot of its activity; on the contrary, for a reason we shall shortly see, it is actually stimulated by cold to more energetic movements.

The temperature of a mammal or bird is never absolutely constant; it shows distinct oscillations, but these oscillations are small and within fairly fixed degrees of temperature. The temperature of a man at 6 o'clock in the evening is generally about $1\frac{3}{4}$ degrees* F. higher than that taken shortly after midnight, but the average temperature remains remarkably constant. When we speak therefore of the normal temperature of a man or any other mammal we mean a temperature which lies well within the daily range of oscillation in health. Thus the normal temperature of a man is given as 98.4 F. in England, but as 98.9 F. in Germany; both are right for both are within the daily range of rise and fall.

Another difficulty in giving a fixed value to the temperature of a homoiothermal animal is the fact that all parts of the body of the same animal have not the same temperature. Stated generally the more central organs are warmer than those nearer the surface, the maximum being found in

*Throughout this chapter temperature is measured in degrees Fahrenheit, as this system, for some inexplicable reason, is more popular in English-speaking countries.

the blood flowing from the liver. As a rule the readings of a thermometer placed in the rectum may be accepted as giving a good idea of the internal temperature of an animal. The following values may be taken as approximately correct for the normal rectal temperatures of various domestic animals:—

horse ...	... 100 —102 F.	cat ...	... 101.7 F.
cow ...	... 101.5—102	fowl ...	... 107—109
sheep ...	... 104 —105	duck ...	... 108—110
pig ...	... 101 —103	goose ...	... 107
dog ...	... 100.2—101.5	turkey ...	... 109

It is interesting to note that the temperature of most homoiothermal animals is only a little below that temperature at which the enzymes act most rapidly; this is doubtless the chief reason why we find such a temperature in the highest evolved animals.

As man and most domestic animals belong to the homoiothermal group attention may be confined exclusively to this class and the methods by which a practically constant temperature is maintained, may be discussed under the headings, the source of heat, the distribution of heat, the loss of heat, and finally the physiological variations in an animal's temperature.

THE SOURCE OF HEAT.—In every living cell of the body heat is produced, but the amounts formed in the smaller organs, such as the salivary glands, may be very minute and scarcely detectable. It is to the skeletal muscles that we must look for the main source of animal heat. In an animal apparently quite at rest the breathing muscles are active and moveover the other skeletal muscles are mostly in a state of tautness or "tone" which implies chemical change and heat production. During violent exercise the heat produced may be so great that the animal cannot get rid of it quick enough and a passing rise in temperature may be noted. On the other hand if an animal is drugged with chloroform, ether, or alcohol, muscle tone is greatly diminished and the animal's temperature will fall unless the surrounding air be kept sufficiently warm. An animal whose muscles are rendered inactive by the poison curare will, if kept alive by artificial respiration, gradually sink to within a few degrees of the temperature of the room and become to all intents and purposes a poikilothermal animal.

Next in importance to the muscles may be placed the liver where chemical transformations are continually occurring most or all of which liberate heat. As has been stated the blood leaving the liver is the hottest in the body. Next in importance to the liver, as heat producing tissues we may place the heart, and the smooth muscles particularly those in the digestive tract.

THE DISTRIBUTION OF HEAT.—The heat produced in any muscle or organ tends by ordinary physical conduction to spread to adjacent organs, but the chief factor in heat distribution is the blood-stream which is constantly perfusing each tissue and organ and passing thence to the heart.

THE LOSS OF HEAT.—The chief loss of heat is from the skin, concerning the structure of which a few words may be said. The skin or integument can be divided for descriptive purposes into two parts. The superficial part is epithelial and is composed of closely packed epithelial cells which are constantly being renewed and pushed up from below and as constantly being shed at the surface. This layer has neither blood vessels nor nerves. Special outgrowths of this layer form hair, feather, nails, claws and the bloodless parts of hoof and horn. The second or deeper part of the skin is formed of connective tissue, is rich in blood vessels and nerves and possesses special sensory nerve-endings. This layer contains two sorts of glands with ducts that pierce the epithelial layer and pour their secretion on the surface. The *sweat glands* secrete a fluid sweat, consisting chiefly of water and containing traces of salts, urea and fatty acids. The *sebaceous glands* secrete a semi-solid, oleaginous substance (sebum) which consists of lipoid and a little protein and water. The sebum acts as a natural ointment keeping the skin and hair soft, and preventing them from being injured by rain and moisture. Both these glands are constantly secreting, though their activity is subject to considerable variations in intensity. In the connective-tissue part of the skin, or below it, we find a layer of fat.

The skin has many functions to perform; it protects the muscles and other organs beneath it from mechanical injury and from rain, strong sunshine, &c.; it helps a little in getting rid of waste matter and excess of water. The skin possesses sensory nerve-endings which are responsive to heat and cold, to injury, and to contact with bodies or to movements of hairs. Only under abnormal and rare conditions can it absorb fluid from without. But one of the most important functions is its blanketing action in keeping the heat of the body from escaping too rapidly and by allowing changes to be made in the rate of heat escape. In the first place the layer of fat already mentioned is a very efficient non-conductor of heat. This layer is, in consequence, enormously developed in those animals which live in the ocean, and particularly in cold latitudes, as, for instance, porpoises, seals, whales, &c. It is also well developed in the pig. The epithelial portion is likewise a feeble conductor especially when it is thick, as it is in the elephant, &c. Then, as outgrowths from the skin, we find in the majority of homoiothermal animals, hair, fur, wool or feathers which act, not so much by their intrinsic feebly conducting powers, as from the fact that they contain large volumes of air enclosed in myriads of tiny spaces. Now air, thus divided, is a very poor conductor of heat and to air is due the chief value of these natural coverings, as well as that of the artificial clothing of human beings.* When a bird ruffles its feathers in cold weather it merely adds to the enclosed air and this acts as an extra layer of clothing. The same action may be observed in many mammals.

Heat is lost from the skin in three ways. First by radiation, in the same way as a fire in an old-fashioned fireplace radiates its heat into the room. Secondly by conduction, that is by warming the air with which the surface of the body is in contact; thus a stove in the middle of a room not only radiates heat, but also conducts heat by warming the adjacent air. Loss of heat by conduction is great when the air is cold, greater when the air is cold and moist, and greater still when the air is cold, moist, and in rapid movement. The third method is by evaporation of water or sweat. Sweat glands are found in great number in man and the horse; very much less in sheep and swine; and still less in cattle, dogs and cats. In man and the horse the amount of sweat secreted is generally just enough to balance the loss by evaporation so that the sweat just comes to the surface of the sweat pores and no more. When the evaporation is checked by certain conditions of the atmosphere, or when excess of sweat is secreted, as in violent exertion, certain diseases and disorders and nervous disturbances, the sweat accumulates and trickles down the surface, particularly from those regions most abundantly supplied with sweat glands.

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* A given volume of flannel or woollen cloth contains a larger volume of air than the same volume of linen or cotton stuff, hence its high value as a clothing material.

The cooling action of evaporation is familiar in the various devices for keeping drinking water and butter cool in warm weather as by porous clay or damp cloth. Evaporation is greater the drier the air and the quicker the air movement. If the air is saturated with water vapour then no evaporation can take place from a moist surface no matter what the velocity of the air is, or its temperature within the limits that occur naturally.

Heat is also lost in the lungs and respiratory passages by warming the air breathed in, or inspired, as also by the evaporation of water from the lining membrane of these tracts. This loss of heat from the lungs, etc., plays a more important part in the feebly-sweating animals (cattle, dogs, cats) than in the sweating (man and horse).

Some heat is also lost by the warming of food and drink which are generally cooler than the stomach which they enter.

The Regulation of Temperature.—We have now to explain how it comes about that all mammals which are found both in tropical and polar regions are able to maintain a practically constant temperature which varies very little with species and variety. We shall find that homoiothermal animals in cold latitudes have an extra thick coating of fur or subcutaneous fat to retain the heat. Some such, as the bat, adopt the artifice of becoming poikilothermal during the winter and spending the cold months sleeping in a sheltered retreat. Then too we are familiar with the seasonal shedding of fur or feathers and the growth of a thicker coat for winter.

But the most interesting problem is the maintenance of a constant temperature from day to day in each animal despite great changes in heat production and the atmospheric conditions that influence heat loss. Most people are familiar with the principle of the common incubator for hatching eggs. Here there is a mechanical arrangement by which, when the temperature rises a little above what is desired, the heat supply is automatically reduced. An instrument on the same principle, but far more delicate, is the thermostat of the chemist which can be kept constant to within a one fiftieth of a degree Fahrenheit. Here too the flame yielding the heat is reduced when the temperature of the thermostat rises only a small fraction of a degree. But the incubator or thermostat must be kept in a sheltered room and cannot be exposed to rain and snow and frost; moreover the combustion in the flame cannot be allowed to fluctuate within wide limits. The superiority of the homoiothermal animal to such a mechanism lies in the fact that not only can it regulate its heat supply but also can regulate its heat loss.

How is the heat supply regulated? When a mammal or bird is exposed to atmospheric conditions that check heat loss and therefore tend to allow the heat of the body to accumulate we find that, through the agency of the nervous system, the muscle tone is reduced and that the animal instinctively avoids strenuous exertion. There is less combustion in the body as can be shown by the diminished consumption of food and the decreased output of carbon dioxide. Conversely when the animal is exposed to cold its muscle-tone is reflexly raised, it instinctively takes exercise, and its consumption of food and output of carbon dioxide may be more than doubled. That play of muscles which we call shivering is a muscular effort for the sole purpose of raising the temperature. A bat waking from its winter sleep resorts to shivering to work up its temperature rapidly and animals in fever show the same thing.

How is the heat loss regulated? An animal may be called upon to do strenuous work irrespective of weather conditions; moreover there is in the resting animal sufficient combustion going on to make the temperature mount up if the heat loss from the skin is seriously interfered with. We shall find in the homoiothermal animal that there are continual adjustments of the heat loss to suit the altered combustion within and the altered state of the air without. In the first place, if, through any reason, it is necessary to check heat loss the blood vessels in the lower layer of the skin contract, so that less blood flows through the skin and less heat is lost by radiation and conduction. We also find in most birds and mammals that the little muscles attached to the roots of the hairs or feathers, contract so that the external coat is ruffled and made therefore a poor conductor of heat. Man possesses these muscles, but their contraction in cold, producing goose-skin, is useless as he has lost in the process of evolution his hairy covering. Many animals reduce the surface of the exposed skin by cowering or huddling the limbs together.

If however the heat of the body threatens to accumulate then various devices can be brought into play to facilitate heat loss. The superficial vessels can be enlarged and the skin flooded with quick flowing blood so that radiation and conduction are increased. In man and the horse sweat can be poured out in great volume over the skin. Further, the breathing may be increased so that loss of heat from the lungs and air passages and even mouth may be increased; this reaction is more marked in the non-sweating animals, witness the lolling tongue and panting respiration of a dog after violent exertion or even when artifically heated.

The exact mechanism by which heat is regulated is not clearly understood. There is undoubtedly in the central nervous system a nerve centre exquisitely sensitive to changes in temperature and from which nerve impulses can pass to the muscles and the blood vessels and glands of the skin.

THE VARIATIONS OF HEAT.—The capability of regulating the temperature within narrow limits varies with different species. In the non-sweating animals and particularly with those that have a thick woolly covering (sheep) or a thick layer of skin-fat (pig), exertion in warm weather may readily bring about an accumulation of heat in the body which is often dangerous. Man and the horse owing to their rich supply of sweat glands are far better off in this respect than cattle. The wonderful endurance of the horse is in large measure due to this provision; it can keep on trotting without any marked rise of temperature whereas a bull after a few rushes mounts up to fever-heat and shows distressed respiration. This same provision is also responsible for the fact that man and the horse can stand temperatures much higher than that of the body, provided the air be dry and in motion. Under these conditions a man can readily stand a temperature above the boiling point of water. If however the air be warm, moist and calm, thus giving little play to conduction and evaporation, violent exertion in all animals will bring about a rise in temperature which is often serious and occasionally fatal.

When an animal is exposed to cold so extreme that it cannot be combated by increased heat formation and decreased heat loss, the temperature of the body sinks, the animal falls into a deep sleep, and eventually dies. Recovery can occur by artificial warming if the temperature has not fallen below 50 degrees F. If a part of the body be frozen, gangrene generally results and the frozen part is lost. As to the highest internal temperature which the animal body can stand the limit usually given is 113 degrees F. The highest authentic case in man followed by recovery was 111 degrees F., which occurred in rheumatic fever.

The temperature of an animal varies slightly with age being higher in extreme youth and also, according to some observers, in extreme old age.

Starvation tends to lower temperature, and the taking of food tends to elevate it. In all diseased conditions where there is acute inflammation a rise of temperature is observed.

In conclusion a few points may be noticed some of which have a practical interest.

Cold is not well borne by animals that are thin or by animals that are small in size. In this latter case the surface of the body is much greater compared with the weight than it is in larger animals.

Clipping or shearing throws a great strain on the heat regulating mechanism particularly in moist, cold weather. Animals may actually show a higher temperature after clipping than before—this means a very great increase in the heat production.

Animals exposed to cold eat more food than if not so exposed, as part of the food is used in the body for heat formation.

Animals that sweat feebly, and particularly those with heavy coats or with much skin fat, are very liable to develop a high temperature; they invariably do so if over exerted.

Moisture in cold air aids conduction, moisture in warm air hinders evaporation.

Air that is moist and warm is specially harmful if impure through defective ventilation.

CHAPTER IX.

Animal Nutrition.

An animal that has reached adult life and is not increasing in weight must nevertheless eat, digest and absorb food which, as we have seen, serves as material for renewal and repair and for the supply of energy. In dealing with this subject it will be advisable to consider, the essential ingredients of food, the adventitious ingredients of food, the essential qualities of food, food required for growth, and finally the composition of various natural foods.

The Essential Ingredients of Food.

1. Repair Food.—Every living cell in the body is in a state of constant repair requiring a continual intake of fresh material. Moreover there are constant losses of complex material from the skin, such as the protein of sebum, hairs, and the outer layers of the skin itself. In lactating animals the secretion of milk is a heavy drain on many constituents of the body. Water is continually being excreted by the kidney, lung, and skin, and salts leave the body in the urine. All these materials must be present in the food consumed.

Water is present in all foods. Hay may contain as much as 13 per cent., oats about 18 per cent., green fodders vary between 60 and 80 per cent., and roots and tubers as much as 90 per cent. If the water taken in these foods is not sufficient then thirst is provoked and water is instinctively taken by the animal. The rule holds with the domestic animals as with man that the water supplied for drinking purposes should be pure and fresh and above suspicion.

Salts of soda, potash, lime, magnesia, phosphorus, and iron are all in the body, are constantly leaving the body and so must be supplied in the food. The various foods eaten by different animals are all fairly rich in salts, but with grazing animals there is sometimes a danger that too little common salt or sodium chloride may be present; for vegetable foods, though rich in potash salts, are poor in soda salts. This is particularly the case the more distant from the sea the grazing country is. Hence the instinctive relish with which most herbivorous animals lick common salt if placed within their reach. In lactating animals there is a considerable loss of lime in the milk, for this fluid contains actually more lime than does lime water. The amount of lime in oats and maize kernels is very small, roots also are somewhat poor in this constituent, but clovers are rich and to a lesser degree the grasses. Animals fed on salt free foods die speedily; even a poverty in one salt constituent will lower vitality and cause emaciation, skin trouble and feeble resistance to disease. Equally dangerous is a salt content much above what is in the animal's natural food.

Protein is a very important repair food for out of protein most of the solid matter of living cells is composed. A certain amount of protein must be taken in food to cover the constant loss through wear and tear of the body machinery. Protein in excess of this amount is used by the animal as fuel food and it is always advisable to have such an excess. Not all the protein eaten is digested and absorbed; this is especially the case when the protein is of vegetable origin, part passing through the digestive tract and leaving the body with the fæces. Carnivores and omnivores obtain rich supplies of highly digestible protein from the animal substances they eat, but vegetable feeders have more difficulty in obtaining their protein.

The following table gives the approximate percentages of proteins in various foods:—

Roots and tubers	$1\frac{1}{2}$—2
Most green fodders	2 —3
Cows' milk	$3\frac{1}{2}$
Clovers and alfalfa	4 —5
Hay from mixed grasses	$7\frac{1}{2}$
Hay from mixed grasses and clovers ...	10
Most grains	$10\frac{1}{2}$—$12\frac{1}{2}$
Wheat bran	16
Meat	18
Cotton seed (whole)	$18\frac{1}{2}$
Flax seed	$22\frac{1}{2}$
Beans and peas	21—34

As has been stated the proteins vary as regards their digestibility. The animal proteins are almost wholly digested but the vegetable proteins show marked differences in this respect. The percentage of protein digested is relatively high—70-88 per cent. in grains, seeds, clovers, legumes, and cereal by-products; medium, 50 to 70, in green fodders, hays and silage; and low, 20 to 45, in straws and potatoes. As a general rule the proteins are less digestible the coarser the fodder. A term frequently employed in animal dietetics is the *nutritive ratio* which means the ratio of the protein in the food to the remaining digestible organic matter expressed as carbohydrate.* Nutritive ratios are described as narrow, 1 to $5\frac{1}{2}$ and under; medium; and wide, 1 to 8 and over. It has been found by experience that animals thrive better on a certain daily protein intake. Animals at rest or doing moderate work require $1\frac{1}{2}$ to 2 lbs. protein per 1,000 lbs. live weight; with severe work, or with growing or fattening animals, or in the case of cows yielding over 16 lbs. of milk *per diem*, or ewes suckling lambs, $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. per 1,000 lbs. live weight are required. It must be clearly understood that only a fraction of what is absorbed from these amounts is required for body repair (in the case of a man less than one-third of the total daily consumption) the remainder being used for energy supply and for the laying on of fat or flesh or for milk production.

2. Fuel Foods.—All vital processes require an expenditure of energy which is derived solely from the food. Moreover the animal's temperature must be kept up, and this, too, must be met by the heat produced from the oxidation of food in the body. The more work an animal does, and the colder its surroundings, the more fuel food is required. The energy value of any food stuff can be calculated by determining the heat produced by burning a definite weight of the substance and measuring this heat. Such a determination is carried out in an instrument called a calorimeter. The unit of heat is the kilo-calorie which is approximately the quantity

* Fat can be expressed in terms of carbohydrate by multiplying its percentage by 2.4.

of heat which will raise one pound of water four degrees Fahrenheit.* The unit weight is the gramme which is roughly one-twenty-eighth of an ounce. In this way tables can be prepared giving the number of calories produced by burning one gramme of each food-stuff. Thus:—

Food. 1 grm., dry.	Kilo-calories.	Food. 1 grm., dry.	Kilo-calories.
Cane sugar ...	... 3.96	Wheat gluten ...	... 6
Starch ...	... 4.2	Mixed hay ...	... 4.5
Cellulose ...	... 4.2	Sugar beets ...	... 3.9
Egg albumen ...	... 5.7	Linseed meal...	... 5
Caseinogen ...	... 5.9	Butter ...	... 9.2
Gelatin ...	... 5.2	Fats and oils...	... 9.4

A correction has to be made in the case of proteins because these substances, unlike fats and carbohydrates, are not oxidised completely in the animal body, and are represented in the urine by urea and other bodies which have a calculable energy value. Making this correction and striking an average for the various proteins, carbohydrates, fats or oils, we may state that—

One gramme of protein will give rise to 4.4 kilo calories.

One gramme of carbohydrate will give rise to 4.15 kilo calories.

One gramme of fat or oil will give rise to 9.4 kilo calories.

A further correction must be made for the amount of each food stuff which escapes digestion. Thus, 1,000 grms. (2½ lbs.) of starch which, if fully digested, would yield 4,183 kilo calories, really yield about 3,760, and the same weight of dry wheat straw instead of giving 4,470 kilo calories only gives about 3,330. It may be definitely stated, however, that the foods absorbed furnish the animal with the exact amount of energy which we can thus calculate and express in terms of heat units. The foods which give energy are fats and oils, carbohydrates and proteins including gelatine.† To these must be added small quantities of nitrogenous bodies, amides, and amino-acids, which are not proteins but which are closely allied to the products formed from proteins during digestion. It will be understood from what has been said that part of the protein is used for repair and part for fuel. Protein must always be present in the food but carbohydrate can replace oil or fat in a large measure.

If an animal eats more fuel food than it requires for heat and work, it either lays on fat or gets disturbances of digestion. If it eats less than is required it becomes emaciated.

3. BALLAST.—In every animal a portion of the food remains undigested, and, by its presence, helps the bowel to force its contents towards the rectum. This undigested residue has been named ballast and is essential for the health of the animal. A rabbit fed on pure protein, carbohydrates, fat, salts, and water will die of inflammation of the bowel, but will live if indigestible material (say horn shavings) be added to its food. Carnivores require little ballast but that little is essential. In dogs the phosphate of lime from bones acts as ballast; in cats the skin or hair or feathers of their victims. In both animals some earth is generally eaten with their food and this acts in the same way. In omnivores, such as man

*More accurately defined, the kilo calorie is the amount of heat which can raise one kilogramme of water from 4 degrees to 5 degrees Centigrade.

†It should be noted that gelatine cannot act as a repair protein, as it does not contain tyrosin or tryptophane.

and the pig, ballast is present in the form of cellulose and woody fibre in the vegetables eaten. Grazing animals eat enormous masses of material which escape digestion and they have special digestive mechanisms to deal with this residue. The coarse fibres in fodders are only feebly digested and even the fine cellulose of vegetable cells only partially so. The silica of plants is also feebly absorbed. If a herbivorous animal be given a fodder poor in fibre or with fibres too finely chopped, digestion is impaired, the contents of the bowel tend to become stagnant and putrefaction by bacteria takes place giving rise to poisonous products which are absorbed. This is well exemplified in cows that "lose their cud" when placed on a fodder too rich and digestible.

4. Organic Acids.—It is doubtful if carnivores require organic acids but omnivores and herbivores certainly do, and grave constitutional disturbances follow upon their disuse. Fortunately all the ordinary vegetable foods are rich in these acids or their salts. Fruits are exceptionally rich in organic acids and to this, as well as their ballast content, is due their beneficial action in man and other omnivores.

5. Flavouring Substances.—If food is unpalatable, no matter how suitable it is in other respects, it is badly digested. The greater the relish with which an animal eats its food the greater is the amount of digestive juices secreted. The palatableness of foods is largely dependent upon the odours or flavours they possess and these are due to chemical bodies which, though they do not come into any of the categories mentioned, are nevertheless essential constituents of normal food.

7. Enzymes.—Carnivores and omnivores do not require any enzymes in their food but with herbivores, and especially the ruminants, these are essential ingredients. As we shall see in the following chapter on digestion, one of the first transformations that food undergoes in the alimentary canal, is an autolysis, or self digestion, by means of enzymes existing in the living cells of plants. Hence it is that fodders which have been steamed or boiled may, under certain conditions, be not so well digested as the natural plant substances.

There are other essential constituents of diet but their exact composition has not been worked out, for mere traces of them are apparently sufficient. It is highly probable that the body is dependent for its supply of hormones on certain chemical substances which are present in food though only in small amounts. The effects of deprivation of these bodies are only seen in laboratory experiments.

Adventitious Constituents of Food.

In the food of carnivores there is little that does not come under the headings already given. In the case of omnivores and herbivores variable quantities of substances are taken and absorbed which are either harmless and pass out of the body unchanged in the urine or have their harmful properties neutralized in the liver and leave the body as innocuous compounds. Herbivorous animals absorb from their food considerable quantities of substances allied to carbolic acid, and other substances allied to camphor, also sugars that have little or no fuel value. Useless mineral matter (nitrates, silicates and sulphates) may be absorbed in small quantities and excreted in the urine.

The Essential Qualities of Food.

Each food must be suited to the species of animal and even to the ndividual. It must have the proper digestibility and palatableness and have the amounts of ballast, etc., to which the species, through myriads of generations, has been accustomed. The essential constituents enumerated above must be present and in the proper ratios to suit the animal's needs. In most, if not all, of the domestic animals, variety in the food leads to better results than if one ration be too exclusively relied on.

If food be insufficient in quantity the animal has to draw on its own fat and flesh which are actually digested in the body by the ferments they contain, and sent into the blood-stream to make good the deficiency. An animal when completely starved loses nearly all its fat, a great portion of its muscle and spleen, a small portion of its heart substance, but hardly any of its nervous matter. During violent exertion an animal rarely eats enough fuel food; it draws on its supply of fat and glycogen (the latter present in the liver and muscles) and makes good the loss in these bodies during the rest which it ought to have after the exertion is over. Underfeeding with any of the above-named essentials will injure the animal, the most common instance being underfeeding with protein in the case of the ruminants.

Overfeeding when it exceeds what the animal can retain as fat and flesh, causes digestive disturbances. Excess of protein (an error which rarely occurs with ruminants) leads to putrefactive changes in the bowel by which poisonous products are produced and absorbed, causing muscular weakness and loss of fat.

Food Required for Growth.

A young animal requires protein, salts, and fuel food, in excess of its repair and energy needs. The milk of each animal suits the needs of the young of that species. Thus comparing cows' milk and human milk, we find in cows' a larger amount of lime salts to suit the quick bone-growth of the calf, whilst in human milk we find a larger amount of lipoid to suit the quick brain-growth of the human infant. Protein in excess of the repair amount is needed for the building of muscle and gland; fuel food for the formation of fat; lime and phosphorus for bone; lipoid for nerve, etc.

Proteins and carbohydrates can be transformed and laid on as fat in a fattening animal. In a pregnant animal the growth of the young *in utero* has to be considered. An animal with rapidly growing wool requires more protein. An animal recovering from fever or starvation requires fuel food and protein in excess.

Constituents of Some Foods.

To give here an extensive list of food-stuffs with their chemical content would be impossible. To obtain such information special treatises on the subject should be consulted. A few food-stuffs may however be given as types; the values, which are expressed in percentages, to be taken as approximate only.

It must be understood that a chemical analysis only gives the percentage amounts of each constituent in a particular food and gives little or no indication how much of each can be actually absorbed by the animal. This is particularly the case with proteins and fibrous residue; a fraction of the latter being digested and a fraction of the former remaining undigested. The absorption of fat and digestible carbohydrate is on the contrary fairly good. It is however always necessary for each food material, not only to be chemically and calorimetrically analysed, but to be administered to the animal and estimations made of the composition and energy content of the fæces so that the amount absorbed and its energy value may be accurately calculated.

Food.	Protein.	Fat or Oil.	Digestible Carbo-hydrate.	Ash.	Water.	Indigestible matter.
Meat	18–19	10–16	..	1–1·8	64–67	..
Cows' milk	3.5	3.5	5	0.7	87	..
Separated milk ..	3.5	0.7	5	0.7	90	..
Eggs without shell ..	12	11	5	1	75.5	..
Potatoes	2.2	0.2	20	1	76	0.8
Cabbage	2.5	0.4	5	0.8	90	0.9
Pasture grass	3.5	0.8	9.7	2	80	4
Hay from mixed grasses ..	7.4	2.5	42	5.5	15.3	27
Oat straw	4	2.3	42.4	5.1	9.2	35
Turnips	1.1	0.2	6.2	0.8	90.5	1.2
Oats	11.8	5	59.7	3	11	9.5
Horse bean	26.6	0.1	50.1	3.8	11.3	7.2
Wheat bran	15.4	4	54	5.8	11.9	9
Cotton seed (whole) ..	18.4	20	24.7	3.5	10.3	23.2

CHAPTER X

Digestion and Absorption.

The alimentary canal can be regarded simply as a tube which passes through the animal from mouth to anus. As the length of this tube is always greater than the length of the animal, it follows that the tube

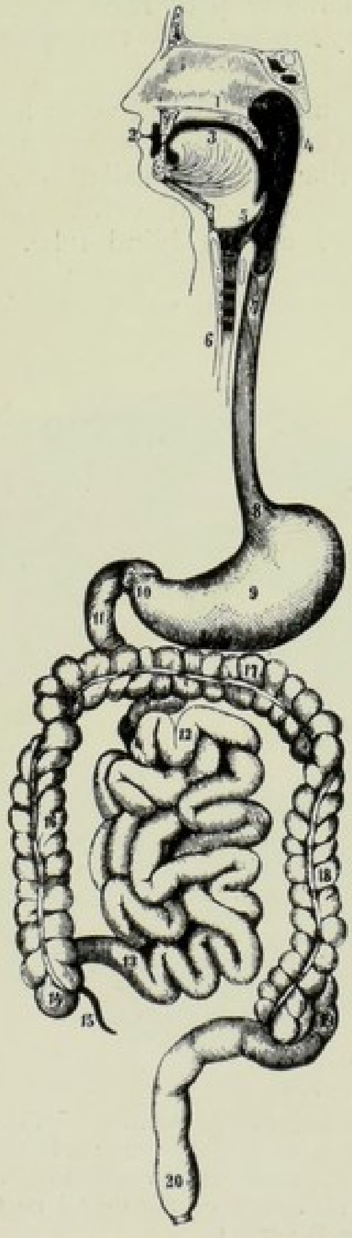

Fig. 42. Diagram of Human Alimentary Canal (After Ellenberger.) 3. Tongue. 4. Pharynx., 7. Œsophagus. 8. Termination of œsophagus. 9. Fundus. 10. Pylorus. 11. Duodenum. 12 to 13. Small intestine. 14. Cæcum. 15. Vermiform Appendix. 16, 17, 18 19. Colon. 20. Rectum.

in some part of its course is coiled. The length, relative and absolute of the alimentary canal varies with each species of animal. We find for instance that the ratio

		Cat.	Dog.	Horse.	Pig.	Ox.	Sheep and Goat
length of alimentary canal		1	1	1	1	1	1
	equals approximately	—	—	—	—	—	—
length of animal		4	5	12	16	20	26

GENERAL ANATOMY.—In the course of the alimentary tube we find some dilatations and constrictions, which mark it off into special parts and to which distinctive names have been given. At the beginning of the canal we find the MOUTH; this opens into a short and muscular part common to the digestive and respiratory systems, called the PHARYNX; then comes a straight narrow portion called the gullet or ŒSOPHAGUS. The lower part of the œsophagus is in some animals dilated forming an organ which is termed the crop or PROVENTRICULUS This opens into the true STOMACH which consists of two parts, the FUNDUS and the PYLORUS.

At this point the alimentary canal becomes a thin and very convoluted tube called the SMALL INTESTINE: the first part of the small intestine which always forms a very distinct loop is called the DUODENUM. The small intestine opens into a dilated pouch called the CÆCUM which in some animals takes the form of a long blind tube. The next part of the alimentary canal commencing at the cæcum is the LARGE INTESTINE or COLON; this merges into the RECTUM which ends in the ANUS.

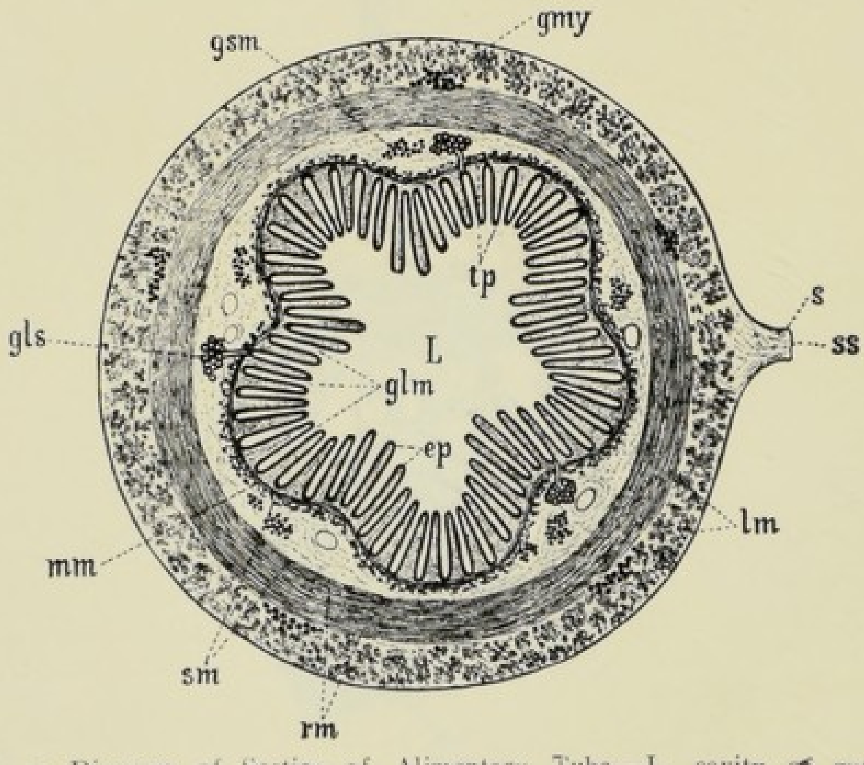

Fig. 43. Diagram of Section of Alimentary Tube.—L, cavity of gut; glm., glands of mucous membrane; ep., epithelium; gls., glands in sub-mucous coat; mm., muscularis mucosæ; sm., submucous coat; rm., circular muscular coat; lm., longitudinal muscular coat; s., serous or peritoneal coat; ss., mesentery; gmy. and gsm., nerve ganglia. (After Sobotta.)

GENERAL HISTOLOGY.—The wall of the alimentary tube consists of several layers. Most central is the lining mucous membrane which extends from lips to anus. The character of this mucous membrane varies in different parts. In the mouth, pharynx, œsophagus and crop it is of the character known as stratified epithelium and functions as a protective membrane only; in the true stomach, cæcum, colon and rectum the epithelium is columnar and is depressed into simple tubular glands (Fig. 45); in the small intestine there are not only these small depressions but between them are elevations or VILLI which markedly increase the surface. Immediately external to the epithelium is a delicate band of smooth muscle called the MUSCULARIS MUCOSÆ which by its contraction can pucker the epithelial layer. External to this is a layer of loose connective tissue called the SUBMUCOUS COAT which allows the epithelial layer some freedom in altering its shape and which generally contains a few mucous glands. The latter secrete a glairy tenacious fluid, *mucus*, consisting chiefly of water, mucin and salts, which is poured on the surface of the epithelium and which acts as a lubricant as well as a protection to the exposed cells. The next layer is a strong band of smooth muscle disposed circularly, whilst external to this is another strong band of smooth muscle disposed longitudinally. In those parts of the tube that lie in the abdominal cavity (crop to beginning of rectum) we have another coat external to this longitudinal muscle called the serous or PERITONEAL COAT which is really a sheet of fibrous tissue thrown round the tube but not completely enclosing it, and continuous with the same sheet lining the inner wall of the abdominal cavity. Thus the tube is slung in the abdominal cavity by a double layer of fibrous tissue, called the MESENTERY, in which run the vessels and nerves supplying the various coats of the tube. The peritoneal or serous coat on its exposed surface is very smooth and is constantly moist, so that the various organs can move about without friction.

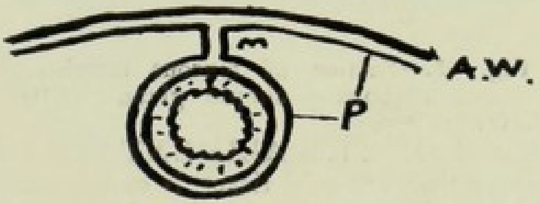

Fig. 44. Diagram to show arrangement of mesentery. A.W., abdominal wall; P., peritoneal coat lining abdominal wall and reflected over gut; M., mesentery.

The structure of the villi deserves some special mention. These projections, which give a velvety appearance to the mucous membrane of the small intestine, are lined, as has been stated, with columnar epithelium; within this is found a layer of blood vessels; within this a thin band of smooth muscle; whilst most centrally is placed a small vessel ending in a knob which vessel belongs to the lymphatic system (to be discussed later) and is called a LACTEAL.

THE GLANDS OF THE ALIMENTARY CANAL.—The mucous membrane of the mouth, pharynx, œsophagus and crop is kept lubricated by small mucous glands in the sub-mucous layer. In the mouth however are found the openings of the ducts of special masses of glandular tissue called the SALIVARY GLANDS. The secretion of these glands is called *saliva* or spittle. In the stomach the tubular glands, described above, secrete *gastric juice*. In the intestines the secretion of the tubular glands is called *succus entericus*. The tubular glands of the colon secrete a large amount of mucus as well as succus entericus.

Opening into the duodenum, or first part of the small intestine, are the ducts of the two largest glands of the body, the LIVER and the

PANCREAS. The duct of the liver has, in most animals (not in the solipeds however), a pear-shaped dilatation called the GALL BLADDER. The secretion of the liver is called *bile*. The pancreas or sweetbread is, in part, firmly attached to the duodenum; its secretion is called *pancreatic juice*.

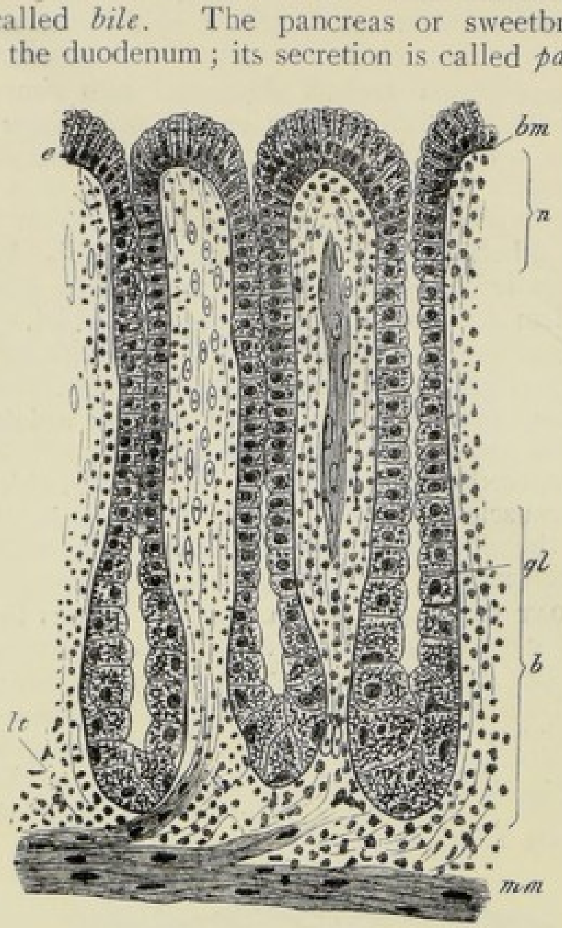

Fig. 45.—Section of mucous membrane of stomach showing simple glands. (After Schäfer.)

ADENOID TISSUE OF THE ALIMENTARY CANAL.—We have seen in a former chapter that adenoid tissue is composed of densely packed cells supported on a connective tissue frame-work. The alimentary canal is fairly rich in this tissue. At the junction of the mouth and pharynx are found two masses of adenoid tissue, one on either side, called the TONSILS. In the mucous membrane of the pharynx many adenoid nodules are found. In the œsophagus, crop and stomach adenoid tissue is present in but small amounts. But in the small intestine we find large nodules of it interrupting the mucous membrane and called PEYER'S PATCHES. The cæcum is also rich in this tissue which in some animals forms a definite outgrowth called the VERMIFORM APPENDIX. Close to the stomach but independent of the alimentary tube, is an organ composed wholly of adenoid tissue and well supplied with blood vessels, called the SPLEEN. Of the functions of these adenoid organs we know nothing.

MOVEMENTS OF THE ALIMENTARY CANAL.—Only in the mouth and pharynx, and in the œsophagus in varying degrees in different animals, and around the anus do we find striped muscle which is under the control of the will. In all other regions of the canal the muscle is smooth and involuntary. The typical movement which the alimentary wall can carry out is a worm-like motion by which the contents of the canal are urged in the direction of the anus. The circular coat of muscle contracts immediately headward of the food mass, and the constriction thus formed is capable of passing like a wave for a short distance down the tube.

At the same time the longitudinal coat helps by contracting, so that the gut wall is pulled over the food-mass. This worm-like action is called *peristalsis*. Peristalsis is rapid in the œsophagus but slow in other regions of the canal. In the œsophagus and in the first part of the colon of most mammals peristalsis can also take place in the reverse direction, namely, towards the mouth.

Another movement that is found in many parts of the canal is a peristalsis of a very weak character, the constriction of the tube being never complete. This movement does not urge the entire food mass onwards; it seems rather to drive forward the most outward layer of the food and to bring a fresh surface in contact with the mucous membrane.

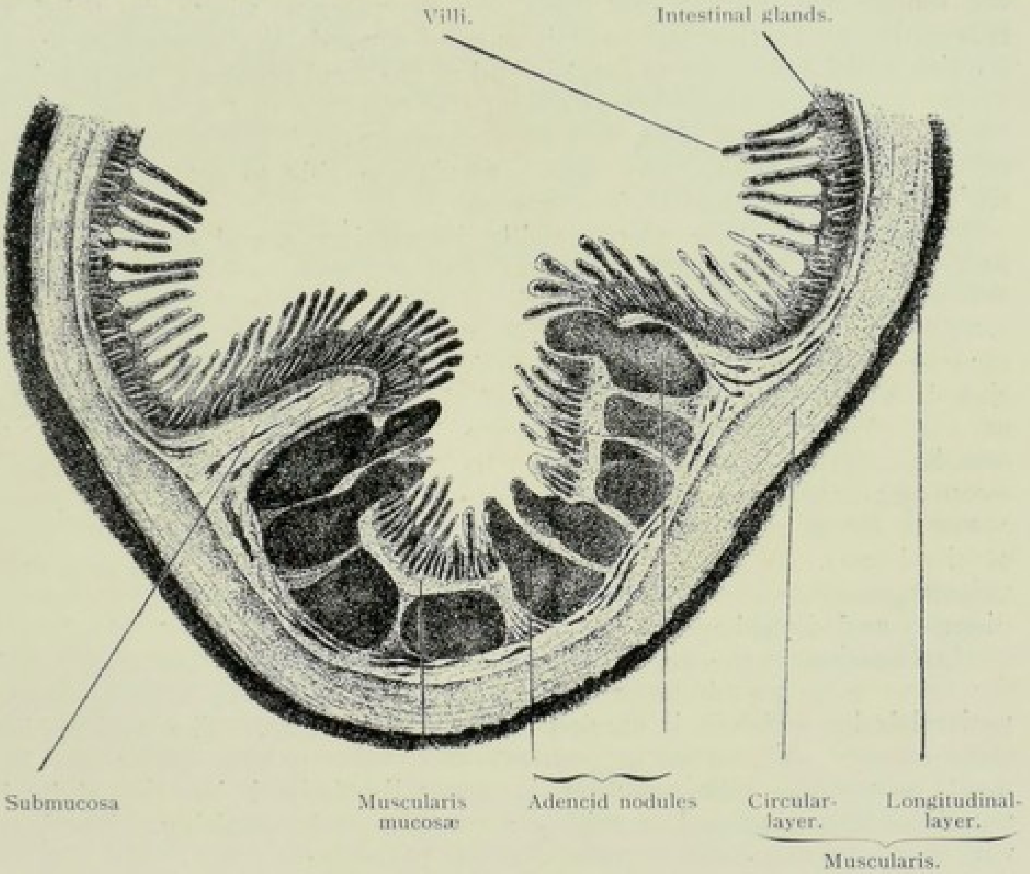

Fig. 46. Transverse section of a patch of Peyer of the small intestine of a cat. The crests of four nodules were not within the plane of the section. (After Stöhr.)

Dilated parts of the canal like the crop, cæcum, colon and fundus of stomach do not show a true peristalsis. On their walls faint waves of muscular contraction may be seen which produce surface currents in the food-mass or rotate the whole. These organs are also capable of strong contraction involving the whole wall so that the contents can be squeezed out.

When a thin part of the canal opens into or out of a dilated part we generally find a strong ring of circularly disposed smooth muscle, really an enlargement of the ordinary circular layer, which maintains a continued contraction and keeps the entrance or exit of the dilated part closed. This muscular ring only relaxes when it is necessary for a food-mass to be driven through and when this is over the ring closes up tightly again. Such rings of muscle are called SPHINCTERS. The external sphincter of the anus is remarkable in that its muscle is striped or voluntary.

The acts of prehension and mastication (chewing) of food are under the will, and are carried out by slightly different methods in different species. The act of swallowing is usually divided into three stages. In the first, which is voluntary, the food, after mastication, is passed to the back of the mouth and into the pharynx. Once the food is in the pharynx the second stage takes place reflexly and independent of the will. A strong peristalsis of the pharynx occurs and the root of the tongue is jerked against the retreating bolus of food. At the same time the hinder openings of the nostrils are closed by the soft palate, and the entrance to the wind-pipe is closed by this being drawn forward under the tongue. By the vigorous muscular action of the pharynx and of the tongue the food is shot into the œsophagus where the third stage takes place. In this the food is carried towards the stomach or crop by a quick and involuntary peristalsis and as the food arrives at the termination of the gullet the sphincter guarding the entrance to the stomach or crop relaxes, lets the food pass, and then closes again. The muscular character of peristalsis explains why most animals are able to eat and drink with their heads lower than their stomachs.

Vomiting can take place readily in carnivores and omnivores but in solipeds it is of very rare occurrence and is almost unknown in ruminants. When a man vomits a deep breath of air is taken and the escape of the air prevented by closure of the glottis. Then the abdominal and thoracic muscles contract vigorously—an action which, if the glottis were not closed, would only drive air out of the lung, but owing to the closure of the glottis the pressure is borne by the abdominal organs. The muscles of the stomach contract too and the sphincter between the œsophagus and the stomach is relaxed. The pressure on the stomach contents forces them along the œsophagus and so into the mouth (nostril of the horse). Vomiting is a reflex generally started by the presence of irritating matter in the stomach, though it may also be due to nervous diseases and disturbances.

Defæcation is the act of extrusion of fæces through the anus. When the fæcal mass accumulates in the lower colon it excites reflexly a strong peristalsis by which it is carried through the rectum. The anal sphincter then relaxes and a strong contraction of the rectum drives the fæcal mass outwards. This action is generally helped by the abdominal muscles contracting and exercising a pressure as in vomiting. Rumination will be discussed under digestion in the stomach.

BLOOD SUPPLY OF THE ALIMENTARY CANAL.—All parts of the alimentary tube are richly supplied with blood vessels that bring red, arterial blood from the aorta. A remarkable peculiarity is present in the parts of the tube that lie in the abdominal region. The blood which has traversed these portions, together with that from the pancreas and spleen, instead of passing into veins that flow direct to the heart, is collected by a system of veins which join into one great vein called the PORTAL VEIN. This portal vein runs towards the liver and breaks up into myriads of branches in that organ so that the blood is brought into the sphere of action of the liver cells. Then from the liver it passes by the ordinary route of the veins to the heart. Thus all the blood drained from the abdominal digestive organs and from the spleen must pass through the liver before it can reach the general circulation. The great importance of this we shall see later.

The lymphatic vessels or lacteals placed centrally in the villi communicate with a smaller number of larger lymphatic vessels and these pour their contents into the largest lymphatic vessel of the body, the THORACIC DUCT, which passes up close to the spine and empties into a vein near the heart.

There are therefore two paths by which a substance, absorbed from the gut, may get into the general circulation; namely by the blood vessels of the gut, in which case it must run the gauntlet of the liver; or by the lymphatics, in which case the absorbed substance can enter the general circulation without passing through the liver, but its progress is much slower owing to the sluggish stream in the lymphatics.

NERVES OF THE ALIMENTARY CANAL.—In the intestines, and to a lesser degree in the crop and stomach, we find a local nervous system which reminds one of that present in the lowest invertebrate animals. It consists of a plexus or nerve-network with ganglia, in between the muscle layers and in the submucous coat. This system can work independently of the central nervous system and can carry out the peristaltic and rippling movements of the walls of the canal. Under normal conditions, however, it does not work independently, but is under the direct subordination of the central nervous system through autonomic nerves. In the first place the thoracic autonomic or sympathetic system sends nerves to the canal from œsophagus to rectum which can exert two functions, they can tighten up or constrict the small arteries in this region, and secondly, can slow down or stop the various movements of the canal muscles. On the other hand we have the cranial autonomic system, through the vagus nerve, innervating the pharynx, œsophagus and all the abdominal portions except the lower colon and rectum. Impulses passing down the vagus increase the muscular movements of the canal and can bring about forceful contraction of the entire musculature of the stomach; they can also start and increase secretion in the glands of the stomach. In the lower colon and rectum the vagus is replaced by sacral autonomics passing out of the spinal cord by the second and third sacral nerves.

The alimentary canal is also supplied with afferent or sensory nerves, giving in the mouth sensations of touch, taste, heat and cold and pain, but, in the main portion of the canal, pain is the only sensation obtainable except the special sensation of thirst and probably of hunger.

The salivary glands in the mouth region have each a double nerve supply, sympathetic and cranial autonomic; the former have fibres which constrict the blood vessels thus lowering the blood flow whilst the latter have fibres which dilate the blood vessels thus increasing the blood flow. Each has fibres acting on the gland cells but their distribution has not been worked out with sufficient clearness. It is known however that certain nerve impulses can influence the composition of the saliva fitting it for the particular substance in the mouth which has reflexly excited its flow.

The nerve centres which regulate the movements of the alimentary canal are all in the medulla oblongata, with the exception of that regulating defæcation which is in the lower part of the spinal cord. They are excitable by appropriate afferent impulses due generally to the food itself; thus food in the mouth starts afferent impulses which excite the centres for the salivary glands and for the secretion of gastric juice; food in the pharynx excites the centre for swallowing; fæces in the rectum excites the centre for defæcation. But the centres are excitable by other afferent nerves and by impulses coming down from the brain. Thus, increased intestinal peristalsis may be caused by fright, and vomiting in the human being may be due to many factors other than those connected with digestion.

THE FUNCTIONS OF THE ALIMENTARY CANAL.—The first important function of the alimentary canal is the digestion of certain ingredients of the food by rendering them soluble, and soluble in such a form that they can pass into the columnar epithelium of the mucous membrane and so be absorbed. The second important function is the absorption of the digested food. These are the fundamental functions but they do not exhaust the list. Thus the lower part of the alimentary canal in all animals has excretory powers, *i.e.*, it gets rid, to some extent, of waste matter or foreign materials from the blood. Further, in many animals, we find some part of the canal functioning as a reservoir of water which can tide the animal over long marches between one drinking place and another.

DIGESTION IN THE MOUTH.—The shape and arrangement of the teeth vary in different animals according to the food they are fitted to eat and their manner of eating. In all mammals the tongue is a muscular organ covered with a rough and thick layer of stratified epithelium; it is richly supplied with end-organs for touch, and at its back has special end-organs for taste.

The saliva is the mixed secretion of a number (generally three pairs) of salivary glands. Its composition varies according to the composition of the substance in the mouth which has excited the flow. Thus sand or an irritating chemical in the mouth excites a flow of very watery saliva suitable for washing the substance away; water excites the flow of a very thick saliva rich in mucin, whereby the water is rendered semi-gelatinous—generally speaking the saliva excited is the best for that particular substance which enters the mouth. Saliva keeps the mouth moist, and by wetting the food can help the teeth and tongue to grind or roll the food into a mass fit for swallowing. In the saliva of omnivores and herbivores, especially when these are eating foods containing starch, the saliva contains an enzyme *diastase* or *ptyalin* which can convert the starch into the sugar maltose. The main ingredients of saliva are water, over 99 per cent., mucin to make the saliva adhesive and viscid, salts, and particularly lime salts, so that the saliva shall not absorb away the lime of the teeth (in fact lime salts are often deposited on the teeth as tartar) and diastase as mentioned. In saliva are also found some round white cells or salivary corpuscles, the function of which is not known. The functions of the mouth as regards digestion are therefore the prehension of food; the mastication of food, by which the surface of the food is increased and the food made into masses fit for swallowing; the selection of food by taste; and the mixing of the food with saliva. No absorption of food occurs in the mouth.

DIGESTION IN THE CROP AND STOMACH.—The food, when swallowed, enters the crop or proventriculus, which, as we have seen, is a dilated portion of the œsophagus. In man and the carnivores this organ is wanting, and the food therefore enters directly the fundus of the stomach. In ruminants the crop is represented by the large RUMEN or paunch (first stomach) with its attendant RETICULUM or honeycomb; in the horse and pig the crop is joined to the fundus without any narrowed portion or neck between. In the crop the food gets warmed up to the temperature of the body, and gets thoroughly macerated with the saliva. Moreover, the diastase of the saliva continues its action on any starch which may be present. A very important action is the digestion of the food by the ferments which it already contains. This autolysis is also aided by harmless bacteria, and in consequence of this combined action, the food mass, which is constantly being rotated and stirred by the movements of the muscular wall, is subjected to a partial digestion which affects most of the food ingredients. Starch is partially transformed into sugar, proteins into proteoses, whilst oils and fats are acted upon only slightly. But the most important action is a semi-digestion of cellulose and woody fibre.

by which the vegetable mass is softened, and the contents of the vegetable cells made more accessible. The carbohydrates in the food produce considerable quantities of acids, like lactic acid and butyric acid; and gases,

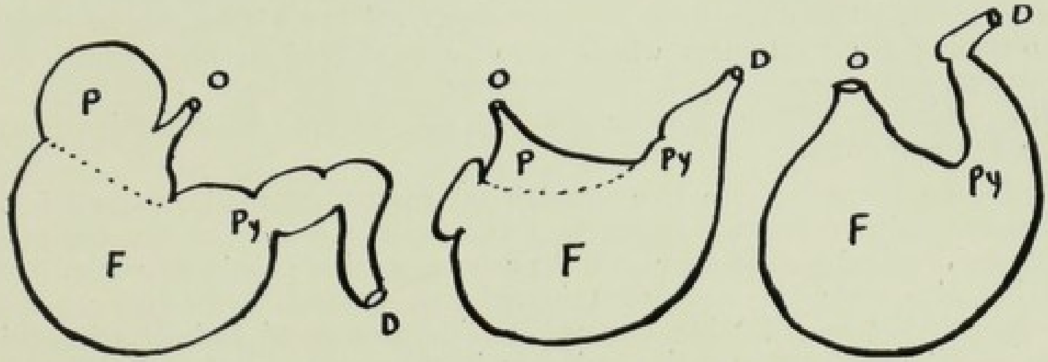

Fig. 47. Diagram of stomach of horse, pig, and dog. O., Œsophagus; P., proventriculus; F., fundus; Py., pylorus; D., duodenum.

like hydrogen and carbon dioxide, are also liberated, so that the whole mass in the crop may have a spongy look and feel. Sometimes, as with young wet clover, the gases produced by fermentation are excessive, and a dangerous distension of the crop (hoven) may be produced.

In the horse and pig, the contents of the crop pass readily into the fundus, the two being practically confluent. But in the ruminants, the passage into the fundus is roundabout, and involves a return to the mouth. In the process of rumination (chewing the cud) the contents of the rumen

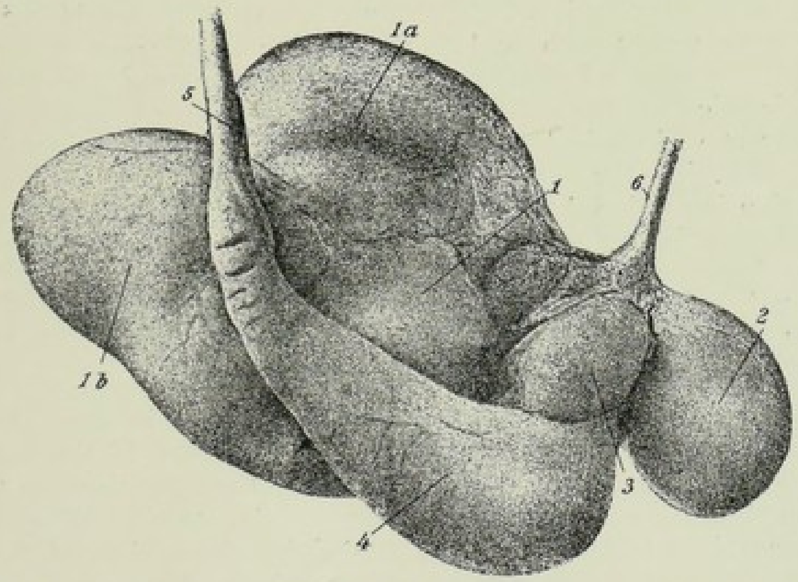

Fig. 48. Proventriculus and Stomach of Sheep. 1, 1a, and 1b, Rumen; 2, Reticulum; 3, Omasum; 4, Abomasum or true stomach consisting of a fundus tapering into a pylorus; 5, Beginning of duodenum. (After Hagémann.)

are forced in small portions at a time into the œsophagus, and by a reverse peristalsis into the mouth. The mass is then subjected to a thorough grinding by the teeth, and is once more swallowed. This time, however, the food mass is not delivered into the rumen by the œsophagus, but by means of a double fold on the roof of the rumen which, closing over, becomes a tube, it passes into the OMASUM or manyplies. The characteristic feature of this organ is the presence of strong muscular leaves lined with coarse stratified epithelium which, by their movements, rasp the food. and if they do not actually break up some of the fibres, at least roll them and work them so that the food mass is fit to enter the remaining portions of the canal. The omasum contains a few glands, but they are of little importance. The reticulum or honeycomb acts as a reservoir of fluid, moistening the food mass which is to be ruminated or passed into the omasum. Its exact significance, however, has not been fully worked out. There is no true digestive secretion, nor is there any absorption from the proventriculus.

In the fundus of the true stomach (abomasum of ruminants) we find that the lining membrane is secretory and capable of pouring out a digestive fluid called gastric juice. Gastric juice consists chiefly of water, but it has also some very important ingredients, namely, hydrochloric acid, pepsin and traces of other ferments. The amount of hydrochloric acid varies with different animals, and even in the same animal with different diets; generally speaking as much acid is secreted as the protein present can absorb, and frequently a little more, making the free acid present equal to 0.2 to 0.4 per cent. The uses of hydrochloric acid are :—

1. To combine with the proteins and so alter them that they can be attacked by pepsin;
2. To act in the duodenum as an exciter of the pancreas, liver and duodenal glands;
3. To act as a bacteria-trap killing many, but by no means all, bacteria.

Pepsin is an enzyme which can transform proteins into proteoses (albumoses and peptones) which latter are much simpler bodies and better able to be absorbed. Pepsin however can only act if the protein be altered by treatment with acid and hence the significance of the hydrochloric acid. Traces of lipase or fat-splitting enzyme are also found in the gastric juice but the activity of this ferment is very small. Another enzyme frequently described as occurring in the stomach is rennin which clots milk, changing the caseinogen into casein; but it is very probable that this action is produced by the pepsin, in fact it seems to be a property of every enzyme acting on protein. In herbivores and omnivores one always gets lactic acid in the stomach, but this most probably is derived from the carbohydrate of the food by fermentative change. Salts are also present, the same as are found in the blood, namely chlorides and phosphates of soda, potash, lime and magnesia.

In animals that possess no proventriculus, namely in man and carnivores, the masticated food enters the fundus directly. If the amount of food be great the gastric juice may not penetrate through the mass for some time and so the saliva may continue to act on the starch. When however the food mass is saturated with the acid juice the action of the saliva on the starch is stopped. In such animals autolysis of the food practically does not occur.

Fats in the stomach are acted upon only very feebly; but as the envelopes of the fat-cells are digested, when the fat is of animal origin, a liberation of the fat occurs so that it is prepared for subsequent digestion. Carbohydrates are unchanged in the stomach with the exception of that due to the saliva before it is acidulated. Summarising the digestive processes so far we may state that in mammals food is ground and its surface multiplied by the action of the teeth. In animals with a proventriculus all food constituents are slightly digested by autolysis and bacterial action, but the main action is a loosening and softening of the fibres and cellulose cell-walls. Complex carbohydrates (polysaccharides and notably starch) are partially broken down into sugars by the action of saliva and by autolysis in the crop. In the fundus of the stomach proteins are saturated with acid and subjected to pepsin; by this means all solid protein that is not retained within the woody envelopes is dissolved or pulped, being broken down into the simpler proteoses.

In addition to these functions we may describe some others. The proventriculus or the stomach itself acts as a reservoir of food so that while the latter may be eaten intermittently (this is especially the case with carnivores) the intestines receive a continuous supply. In most animals the stomach never becomes actually empty and, by this reservoir action, can tide the animal over short periods of starvation. Another important action is the dilution of strong solutions down to a fixed concentration, or conversely, of strengthening weak solutions up to the same standard. Thus a syrup of sugar or a draught of Epsom salts is diluted, but pure water has salts added to it. This is an important action for the delicate lining membrane of the intestine is readily disturbed by concentrations above or below the standard.

It is very doubtful if any absorption occurs before the small intestine is reached except as regards highly diffusible bodies such as alcohol, &c.

The glands of the stomach are stimulated into action in a twofold manner. In the first place, they are responsive to nerve impulses passing down the vagus nerve from the brain. Whenever an animal is hungry and sees food, or sees preparations being made for a meal, a secretion of gastric juice occurs reflexly. Just as the human mouth will proverbially water at the bare mention of anything appetising, so the gastric glands will secrete when anything even suggests food, provided the animal be hungry. The more appetising the meal, and the more eagerly it is eaten, the greater will be the secretion of gastric juice. If the pleasure of eating be interfered with, as by fright, strange surroundings, pain, or unaccustomed interruptions, the flow of gastric juice will be much less than the normal, and may be practically absent. The mere act of chewing food will, if it be accompanied by ordinary pleasurable sensations, also provoke a flow of gastric juice. Owing, then, to this nervous mechanism the food mass, entering the stomach, finds this organ ready for digestion and is subjected at once to the action of hydrochloric acid and pepsin. This description of the nervous reflex *via* the vagus has been proved experimentally to be true for man and the carnivores, but it is doubtful how far it applies to the herbivorous animals and particularly to the ruminants. The act of grazing in the latter class is apparently unaccompanied by any gastric secretion, but it seems to be universally admitted that the more content a beast is, the better does it assimilate its fodder. It is probable that the nervous reflex is present in ruminants during the act of chewing the cud. The second method by which the stomach can be excited to secretory activity is by the food itself. The protein of the food, meeting the juice already secreted through the nervous (psychic) reflex, is partially digested and the products of digestion have the power of further stimulating the gastric glands, most probably by producing a hormone in some portion of the stomach wall. It seems probable, however, that certain constituents of some foods can excite the gastric glands without undergoing peptic digestion. The flesh (meat) of the ox, sheep, and pig, contain some such stimulating substance. White flesh, such as that of the rabbit, contains very little. Dextrin formed from starch by the action of the saliva also has some excitant action, but whether directly, or by hormone formation, has not been definitely ascertained.

The pylorus of the stomach is characterised by strong peristaltic waves that drive the stomach contents, when these become sufficiently pulped or digested, through the pyloric sphincter into the duodenum. The glands with which the pylorus is supplied act chiefly by adding some more pepsin to the food; they do not add acids as the proteins have already been saturated with hydrochloric acid in the fundus.

DIGESTION IN THE SMALL INTESTINES.—In the duodenum the food mass or *chyme* as it is called, encounters the pancreatic juice and the bile, concerning the secretion of which a few words may be now said. In the wall of the duodenum is a substance called *prosecretin* which is held fast by the epithelial cells. When, however, this substance comes into contact with an acid it is changed into another body called *secretin* which is liberated by the cell, is caught up by the blood stream and so reaches eventually all parts of the body. Now secretin is a true hormone or chemical messenger, for it acts on the pancreas causing this to secrete pancreatic juice; it also acts on the liver causing this to secrete bile; and it probably acts on the duodenal tubular glands causing these to secrete *succus entericus*. The mechanism is therefore simple. The stomach content or chyme is acid; it liberates therefore secretin; the pancreas and liver are stimulated therefore to secrete and, as their secretions are alkaline, it follows that they will continue to be stimulated until the acid of the chyme is neutralized; when this happens no more secretin will be formed and the activity of the pancreas and the liver will come to a halt. But when a fresh squirt of chyme is sent into the duodenum the same cycle will start over again.

The pancreatic juice is in many respects the most important digestive secretion in the body. It contains the following ingredients besides water and a little protein:—

1. *sodium carbonate*, about 0.6 per cent., which neutralises the acid of the chyme, emulsifies the fats and oils and to which the alkalinity of the juice is due,
2. *lipase*, called also *steapsin* which splits fats into fatty acids and glycerine,
3. *diastase* called also *amylopsin* which transforms starch and dextrins into the sugar maltose,
4. *erepsin* which transforms proteoses into amino-acids,
5. *protrypsin* a proferment which has in itself no action, but which, by coming into contact with a constituent of the succus entericus called *enterokinase*, is transformed into trypsin a remarkably powerful ferment, which changes proteins into amino-acids.

The bile is a fluid of a yellow or greenish tint and with a characteristic taste. It contains, besides some 92 per cent. of water and in most cases a little protein, the following bodies:—

1. *bile salts*, which are compounds of sodium and potassium with complex organic acids (*glycocholic* and *taurocholic acids*). The importance of these salts is to be found in their power of dissolving fatty acids which would otherwise be insoluble. These salts being alkaline also help in neutralising the chyme,
2. *pigments*—to be looked on as excreta and probably due to the broken-down red colouring-matter of the blood,
3. *lipoid*—probably from the corpuscles of the blood and to be looked on as waste matter.

The succus entericus of the duodenum and small intestines is a more dilute fluid containing besides mucin:—

1. *enterokinase*, which transforms protrypsin into trypsin,
2. *erepsin*, which transforms proteoses into amino-acids,

3. *maltase*, which transforms maltose into glucose,
4. *lactase*, which transforms lactose into glucose and galactose,
5. *invertase*, which transforms cane sugar into glucose and levulose.*

The chyme, neutralised and mixed with bile and pancreatic juice, is urged along the small intestine by peristalis, receiving succus entericus on its way and having a certain amount of digested material absorbed from it. The course of digestion here may be summarized as follows:—The undigested and semi-digested proteins of the chyme are attacked by trypsin and disintegration into amino-acids commences. The proteoses present undergo the same change through the presence of erepsin. Fat is split by the lipase into glycerine and fatty acids which latter are dissolved by the bile. Starch and dextrins are broken down into sugar by the diastase and compound sugars are split into simple sugars by the ferments of the succus entericus. The sojourn of the chyme in the small intestine is not nearly long enough for these changes to be completed; the ferments are added and the action begun but the completion of the process takes place in the lower tracts of the bowel.

Absorption in the small intestine can be shown to be undoubtedly present and affecting all classes of food but especially the fats and sugars. The fatty acids dissolved in bile, together with the glycerine, are absorbed by the lining cells and recombined into fat. The fat in the form of small globules is carried by white cells capable of movement into the central lacteals of the villi and thus sent into the circulation by the lymphatic system. A small portion does not do so, however, being either absorbed directly in the blood stream and sent on to the liver, or retained as fat in the gut wall. The simple sugars, dextrose, levulose and galactose, and the products of protein digestion are absorbed as soon as they are formed and come in contact with the villi of the mucous membrane. The path of their absorption is undoubtedly through the blood vessels passing thence to the portal vein and liver, but the fate of these digested products is rather shrouded in mystery. The little that is known may be briefly epitomised as follows. There undoubtedly occurs in the liver a break-up of part of the amino-acids into urea and carbon compounds, the former being excreted by the kidney, the latter being used as fuel-food or stored as such. In the liver also a polysaccharide called glycogen can always be found. This glycogen increases in amount after the administration of a food rich in carbohydrate and diminishes when the animal is actively exercised. Now glycogen is readily transformed into glucose and glucose is found in the blood, but never above a certain small percentage, and it has therefore been suggested that the liver, by means of its glycogen store, keeps the sugar content of the blood up to its normal figure. Part of the digested protein is reformed into true protein taking its place as such in the blood but where this occurs whether in the bowel wall, in the blood, or in the liver, is difficult to say. Sugars can be changed, as above stated, into glycogen but this change accounts only for a fraction of the total amount absorbed, the rest may probably be altered into fat but in what organ we do not know. An extraordinary fact bearing on this problem of absorption is that, when the pancreas is removed from an animal, or if it undergo degeneration as a result of any diseased condition, sugar appears in quantity in the urine, the animal becomes emaciated and finally dies. This condition is known pathologically as *diabetes* but of its origin and significance we know nothing. Water is absorbed to a

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* Recent research has shown that lipase and diastase are present in small amounts in the succus entericus.

slight extent in the small intestines making the contents less fluid than the chyme. The bile salts are absorbed, returned to the liver, and neutralised by that organ. The cholesterin apparently escapes absorption.

The activity of the small intestine is governed largely by the food. Each compound sugar for instance, can excite the secretion of the appropriate ferment; and the texture of the food can influence the rate and intensity of peristalsis. But the central nervous system has a considerable control over the small intestine. Thus during active exercise, when a large number of muscles are employed, the blood vessels of the intestine constrict and digestion is checked; moreover the emotional state of the animal has, as is well known, considerable influence, whether favourable or unfavourable on digestion.

DIGESTION IN THE CÆCUM.—The cæcum is small in carnivores and man, of moderate size in ruminants and the pig, and very large in the horse. The entrance from the small intestine is controlled by a sphincter called the *ileocæcal sphincter* which in some animals is guarded by a valve-like fold of mucous membrane. In carnivores and man the cæcum functions as part of the colon; but in solipeds, ruminants and the pig, it is a digestive organ of considerable moment. Perhaps the longest sojourn that the food mass makes in its passage through the alimentary canal is made in the cæcum of these animals. In the solipeds its huge size marks it out as having special functions to perform; in fact when we compare the process of digestion in the horse with that in a ruminant we shall find that in the former animal the proventriculus is comparatively small whilst in the cæcum occurs most of the change which takes place in the rumen of the ruminants, with this exception, that in the cæcum autolysis is not present but is supplanted by the action of ferments brought with the food from the small intestine or excreted by the cæcal mucous membrane. Bacteria also flourish in the cæca of all mammals and it is a matter of debate whether their presence is not absolutely essential. Bacteria certainly help in continuing the digestion of proteins, carbohydrates and fats, but they can also act in a manner not beneficial. Thus a part of the carbohydrate becomes changed into gases, hydrogen, marsh gas, &c., and so loses its nutritive properties; and further, from the protein of the food, evil-smelling, poisonous products are formed which are absorbed by the blood and carried to the liver where they are altered and their toxicity removed. This safe-guarding action is one of the chief functions of the liver and accounts for the very rapid onset of death after loss of this organ.

If there be excess of protein in the food, or if its absorption be delayed, then toxic bodies are produced in greater quantity than the liver can destroy, and they therefore get into the circulation producing muscular weakness, loss of fat, and general decline in health.

The cæcum secretes some ferments, and notably one that can digest and dissolve cellulose and woody fibre. The importance of this ferment does not lie so much in the cellulose becoming fuel-food as in the fact that, in the food that reaches the cæcum, much protein, fat and carbohydrate has remained unaltered through being enclosed in cells or lying between tough woody-fibres. In the cæcum these bodies are liberated, and their digestion begun. In the non-ruminating animals with small cæca, digestion of cellulose, if it occurs at all, must do so to a very limited extent. We may look on the cæcum therefore as an organ for continuing digestion. It probably has a little absorbing power. In the horse it functions as a water reservoir, serving the same purpose as the reticulum of the ruminant. When a horse drinks the water is said to pass rapidly through the stomach system, and even through the small intestine to be poured into the cæcal cistern.

DIGESTION IN THE COLON.—The colon varies in a remarkable manner in each species of animal, and little is known of the parts that are analogous in one species as compared with any other. Certain points as regards digestion in the colon may be given as definite—

1. Digestion continues and is terminated. It is doubtful if the succus of the colon has high digestive properties; most of the glands seem to turn out mucus which lubricates the lining membrane. Bacteria decrease in number in the colon as the rectum is approached.
2. The colon is the main absorbing portion of the whole alimentary tract. This is especially true as regards water, the fluid food-mass changing to semi-solid even solid fæces. Proteins are well absorbed, and to a lesser degree the carbohydrates and fats.
3. The colon is an excretory organ. In starvation, or when the lower part of the colon is disconnected from the rest, it will be found that some fæces are passed. Experiment also shows that many substances, particularly metallic salts, leave the body by this channel.

THE FÆCES.—In the lowest part of the colon the fæces collect, and are moulded into the form characteristic for the animal. When the fæcal mass has reached the rectum, the act of defæcation is excited reflexly. The fæces consist of the indigestible and partly-digested portions of the food together with mucin and excretory products from the colon wall, altered bile pigments, cholesterin, remains of bacteria, and products formed by these. The character of the fæces depends on the species of the animal as well as the nature of the food, and the rate of peristalsis and absorption. The smell of fæces is due to bacterial products chiefly, and is especially offensive when the food contains excess of protein and too little ballast. The colour is partly due to altered bile pigment, and, in the case of vegetable eaters, to the altered chlorophyll or green colouring-matter of plants.

CHAPTER XI.

The Blood

The blood is a red opaque fluid which circulates through a system of tubes called blood vessels. Its functions are—

1. To carry oxygen and nutriment to the tissues.
2. To carry carbon dioxide and waste products from the tissues.
3. To distribute heat, equalizing it through the inner organs and preventing local or general rise of temperature.
4. To carry chemical messengers or hormones from organ to organ.
5. To resist the attacks of bacterial parasites and to neutralize their poisons.

The blood consists primarily of a straw-coloured, transparent fluid called PLASMA in which are suspended structures called CORPUSCLES. The plasma occupies about two thirds of the volume of the blood and consists chiefly of water namely about 90 per cent. Of the solids present proteins, in the form of albumens and globulins make up about 8 per cent. Small amounts of sugar and fat can also be detected and traces of waste matter such as urea, uric acid, &c. The mineral ingredients, constituting about 0.9 per cent, are made up of chlorides, phosphates and bicarbonates of soda, potash, lime and magnesia. The metals with which these acids are combined are present in a constant proportion, nearly the same proportion that exists in sea water, and their importance is considerable. An organ,

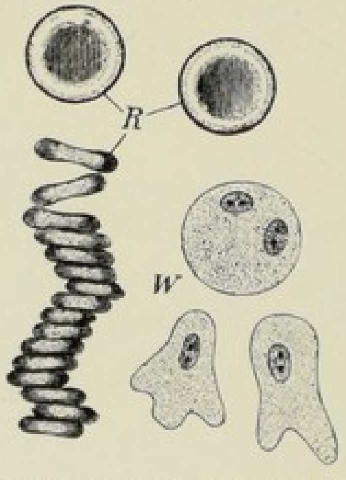

Fig. 49. Blood corpuscles, highly magnified; R., red; W., white. (After Hagemann.)

say the heart, loop of bowel, uterus, &c., cut out of a recently-killed animal, can be kept alive and maintained in an active condition for many hours if a solution of these salts, in the proper proportion, is pumped through its vessels. Water alone or any watery solutions containing other than the correct concentration and proportion of these salts will speedily cause the death of the organ.

The corpuscles are of two kinds red and white. The RED CORPUSCLES are tough, elastic discs of microscopic size. Viewed from one aspect they appear circular, but looked at end-on they are dumb-bell shaped. Mammalian corpuscles do not possess nuclei and cannot be regarded as living; in fact there is evidence to show that they are continually being broken down and replaced by fresh ones in the marrow of certain bones. Their size (diameter of the disc) varies slightly with different mammals and probably also in the same species. The following table gives approximately the diameter of a number of types:—

Man	$\frac{1}{3200}$ inch.
Dog	$\frac{1}{3500}$,,
Pig and Ox	$\frac{1}{4200}$,,
Horse	$\frac{1}{4500}$,,
Sheep	$\frac{1}{5200}$,,

The number of corpuscles present is usually stated in terms of the number present in a cubic millimetre* of blood. Thus—

Horse, 6,500,000—8,000,000 red corpuscles per cubic millimetre.

Man, ox, pig and dog, about 5,000,000 red corpuscles per cubic millimetre.

Goat, 9,000,000—10,000,000 red corpuscles per cubic millimetre.

The red corpuscles are composed of an external envelope of lipoid within which is a meshwork of protein holding in its spaces the red colouring matter of the blood or *hæmoglobin* which constitutes over 30 per cent. of the weight of the corpuscle. Hæmoglobin is a complex protein containing iron, and seems to be present in the body for the sole purpose of carrying the oxygen and part of the carbon dioxide. The red corpuscle may therefore be looked on as a boat for the transfer of the two blood gases, and this property it possesses through its hæmoglobin content. When hæmoglobin is linked to oxygen, forming *oxyhæmoglobin*, its colour is bright red; if uncombined with oxygen (simple *hæmoglobin*) its colour is bluish-purple. Hence the blood leaving the lung and that in the arteries (arterial blood) is red, whilst that leaving the tissues (venous blood) is bluish-purple. When red corpuscles are placed in water or in a salt solution of less than the proper concentration, they swell up and burst, liberating the hæmoglobin into the fluid. If placed in a salt solution stronger than the blood they shrink and crinkle at the edges. Anything which dissolves or breaks up lipoid (chloroform, ether, &c., and certain toxic enzymes) will destroy the integrity of the corpuscle and liberate the hæmoglobin; and it is important to note that hæmoglobin, thus liberated, acts as a foreign body, is incapable of carrying the gases properly, and is promptly turned out of the blood by the kidney. The red corpuscles, as has been stated, are elastic. They pass with ease through the pores of fine filter-paper and can be forced through tubes or apertures of smaller calibre than their diameters.

The WHITE CORPUSCLES, unlike the red, are nucleated living cells, some of which move to and fro in the plasma and are capable of passing through the walls of the smaller blood vessels. The number of white cells is much less than that of the red; in man, for one white, 500 to 600 red can generally be found. There are several varieties of white corpuscles, and it is probable that they may have different functions. The most numerous sort are endowed with the power of attacking and digesting bacteria just as an amœba can digest a particle of food. If bacteria get lodged in a tissue the white cells throng to the spot and a fight for life or death ensues. What is known as pus or matter is most probably a collection of white cells which have been exhausted if not killed in the struggle. This contest between the white cells and intruding bacteria is probably in constant operation. It is only when bacteria get temporarily

* A cubic millimetre is approximately one-fiftieth of the volume of a drop of water.

the upper hand that inflammation, with all its signs and symptoms, takes place. These white cells can not only digest bacteria but they can also eat away and remove small blood-clots and small portions of tissue that have died through injury or stoppage of the circulation. White cells undoubtedly play some part in digestion as their number is always increased after a meal. That they can carry fat globules from the surface cells of the villus into the central lacteal is undoubted; probably they help also in the absorption and rebuilding of proteins and carbohydrates.

Both varieties of corpuscles are slightly denser than the plasma in which they float. If blood be kept in a vessel and prevented from clotting the corpuscles will sink by gravity; this action can be hastened by the centrifuge, an instrument on the same principle as the cream separator, only that in this instance the corpuscles, unlike the cream, are slung outwards.

THE CLOTTING OF BLOOD. — The spontaneous coagulation or clotting of blood serves as a natural means of arresting hæmorrhage. Were it not for this property, a small and unperceived cut would continue to bleed until death resulted. The essential change in blood clotting is a transformation of a soluble globulin called *fibrinogen*, which exists in a small amount in the plasma, into an insoluble, stringy substance, *fibrin*. When blood clots as a whole the fibrin meshwork entangles the corpuscles so that the clot consists of fibrin and corpuscles together. Such a clot at first extends over the whole mass of blood affected, but very soon a clear fluid will be seen exuding from the clot; this fluid is *serum* and is really plasma bereft of its fibrinogen. If, while blood is clotting, it is stirred briskly with a bunch of feathers, the fibrin is collected into a mass and does not entangle the corpuscles. Such blood is called *defibrinated blood* and when it is centrifuged or allowed to settle it separates into corpuscles and *serum*. If blood be separated into plasma and corpuscles before clotting has taken place, then the clot will form in the plasma and of course will contain no corpuscles.

The change of fibrinogen into fibrin is conditional on the presence of an enzyme called *fibrin ferment*. But this enzyme does not occur as such in the blood. It is there in an inactive form called *thrombogen*. Now before thrombogen can change into fibrin ferment, two conditions must be fulfilled —firstly there must be *lime salts* present and secondly there must be a substance called *kinase* which is produced whenever a tissue is torn. The interaction of these factors can be given in a simple diagram.

Kinase ... ... Thrombogen ... Lime salts ...	} fibrin ferment ...	} fibrin or clot
	fibrinogen	

The coagulation of blood may be prevented or delayed by cold, which depresses all chemical change; and further by the removal of any of the precursors of fibrin. A favourite method is to add to blood, as soon as it is shed, some sodium oxalate or sodium citrate which removes the lime. Such blood can be centrifuged and plasma obtained from it. On adding to this blood, or its plasma, sufficient lime salts, *e.g.*, calcium chloride, a clot forms very quickly. Leeches prevent clotting around the point of their puncture by destroying the thrombogen, some snake venoms prevent clotting by destroying the kinase. If blood be received into a vessel smeared with oil or paraffin, clotting is greatly delayed; the reason for this is not clearly understood.

IMMUNITY.—Whenever a cell, a protein, or a ferment, foreign to the body, enters the blood, it provokes the formation of a neutralizing or antagonistic substance. The exact site of origin of these substances is not fully understood, one school regarding the white cells as the sole source, another school asserting that the tissues affected by the foreign substance supply the antibody. These antagonistic substances are of various sorts and can be briefly enumerated as follows:—

1. Foreign proteins excite the formation of *precipitins*, which when mixed with the exciting protein produce precipitates. Thus if white of egg is injected several times into a rabbit the blood of this animal will contain a precipitin which can readily be demonstrated by mixing egg white with the rabbit's serum. These precipitins like all the other antibodies are fairly specific. For instance the precipitin evoked by the albumen of a hen's egg will give a well defined precipitate with the white of a hen's egg but none or hardly any with the white of a duck's egg. The proteins of man's blood will excite in the same way a precipitin which reacts best with a protein derived from a man or anthropoid ape.
2. Enzymes excite the formation of *antienzymes*. Even the digestive ferments in the alimentary canal of an animal provoke in the same animal the formation of antitrypsin, &c., which fact partly explains why these digestive ferments act only on the food and not on the lining walls of the gut.
3. The toxins which bacteria produce and which can gain admittance to the general circulation, giving rise to various disturbances, excite the formation of *antitoxins* which neutralise these bacterial products.
4. Foreign cells, including bacteria and foreign blood corpuscles, excite the formation of a number of antagonistic bodies—
   (*a*) *Agglutinins*, which cause the foreign cells to clump together.
   (*b*) *Opsonins* which so act upon bacteria, &c., that these latter are readily devoured by white cells.
   (*c*) *Cytotoxins* which break up the cell-wall and cause disintegration of the cell. Thus the red copuscles of a sheep, injected into a rabbit, will be followed by the formation in the rabbit of a substance which destroys the envelope of the red corpuscles of the sheep and acts only in a feeble manner on the red corpuscles of other animals.

When an animal acquires a disease and, after its recovery, is no longer liable to contract the same disease, as occurs, for instance, with typhoid fever in man and distemper in dogs, the immunity acquired is explained by assuming that these antibodies, formed during the disease, remain in the circulation and effectually prevent each new invasion from making any headway. No substances simpler than the proteins or the enzymes appear capable of exciting the formation of antibodies; thus *ricin*, the poisonous protein of castor-oil seeds, causes the production of antiricin, but alkaloids such as morphia or strychnine or other and simpler substances cannot act in this way.

The total amount of blood in the body is about one-fifteenth to one-twentieth of the total weight of the animal.

The specific gravity of the blood is about 1056, that is to say 1056 volumes of pure water would weigh the same as 1000 volumes of blood.

The reaction of the blood is that of pure water, namely, neutral.

The freezing point of blood also remains wonderfully constant, namely 0.56 C. below that of water for mammalian blood.

CHAPTER XII.

The Circulation

The heart is in reality a double pump, the right and left portions having no direct communication with one another. In each half there is the thin-walled AURICLE, into which the blood is poured from the veins. The auricle in each case communicates with a chamber with more muscular walls called the VENTRICLE; the opening between the two being guarded by a valve so that the blood can pass from auricle to ventricle, but not in a reverse direction. This valve is formed by two flaps in the *left* half, and is called therefore the BICUSPID VALVE, or, from a fancied resemblance to a bishop's mitre, the MITRAL VALVE; but by three flaps in the *right* half, and called in consequence the TRICUSPID VALVE. Each valve flap is firmly attached at its base to the junction of auricle and ventricle and has the free end pointing towards the ventricle. These valve flaps are stayed with tendinous cords—CHORDÆ TENDINEÆ—which are fastened at one end to the edges of the flaps and at the other end to muscular outgrowths from the inner walls of the ventricle. Out of each ventricle proceeds an artery with tough fibrous walls. This opening is also guarded on each side by a valve, but the arrangement of the flaps is different from that found in the mitral and tricuspid valves. Each of these valves is formed by three pouches, the free edge of each pouch pointing away from the ventricle. The shape of these pouches has given the name SEMILUNAR to these valves.

The heart, as every one knows, beats rhythmically, that is, there is a period of muscular activity called *systole* followed by an interval of rest called *diastole*. The movements that take place in systole in a mammal are too quick for the eye to follow; but mechanical records of these changes, as well as comparison with the slower beating hearts of lower animals, allow us to give the following description:—Systole commences in the great veins, close to their junction with the auricle, and takes the form of a wave of muscular contraction rather suggesting a quick but imperfect peristalsis. When the wave reaches the auricle the thin walls of this chamber contract in a short quick "snap." Then the muscular wave passes through the connecting substance between auricle and ventricle and reaches the ventricle, which at once goes into powerful contraction. This sequence occurs on each side in the same manner and at the very same time. When the contraction of the ventricle is over the heart passes into diastole.

It is still a matter of debate whether this muscular rhythm is produced by a local nervous system residing in the heart, or is to be looked on as a property of the muscular substance itself. The nerves passing to the heart from the central nervous system may be severed without stoppage of the heart; the heart may even be cut out of the body, yet so long as its vessels are supplied with blood or a saline solution of the proper concentration, it will beat for many hours. Even certain portions of the heart, if isolated, will exhibit the same property. But the central nervous system, though it is not the cause of the beat, can certainly exercise some control over it. Two sets of nerve fibres pass into the heart. In the vagus nerve there are cranial autonomic fibres which can slow down the rate of the beat and also diminish the force of the ventricular contraction. The heart is normally under some vagus control, for if these nerves be cut the beat at once increases in strength and rate. Impulses can also pass down the vagus due to reflex action. Thus a blow on the stomach or wind-pipe, or an irritating gas getting into the upper air passages, will cause stimuli to be sent down to the heart slowing and weakening it. The other set of nerves is a supply of fibres from the thoracic autonomic or sympathetic system which has just the opposite action on the heart, namely, quickening the beat and strengthening the force. The increase in rate and strength of the heart beat during exertion,

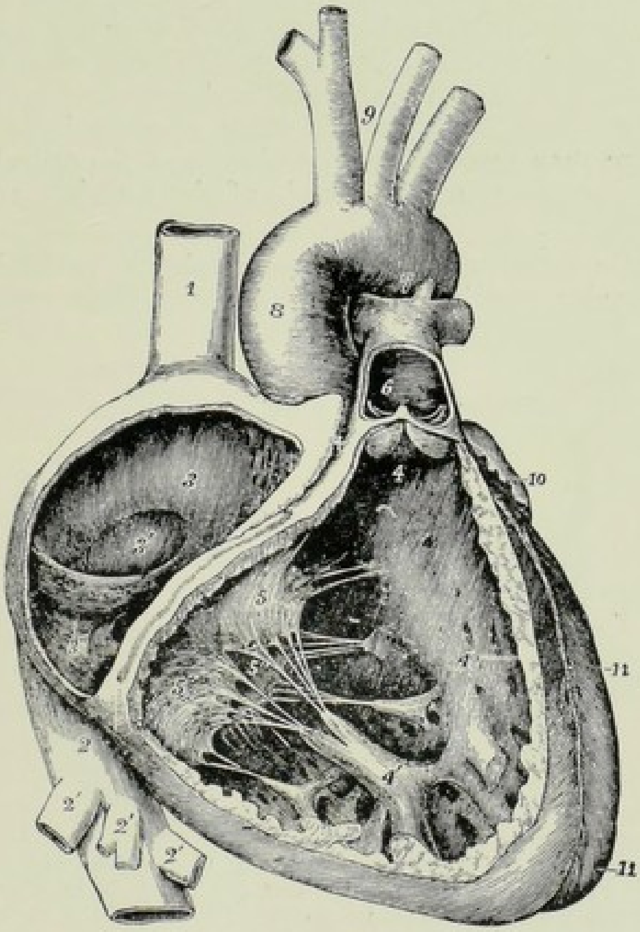

Fig. 50. The heart with the right auricle and right ventricle opened by dissection. 1, 2, venæ cavæ entering left auricle; 3, right auricle; 4^1, muscular pillar attached to chordæ tendineæ; 5, flaps of tricuspid valve; 4, semilunar valve guarding entrance to; 6, the pulmonary artery; 8, aorta; 10, portion of left auricle. (After Halliburton.)

or accompanying fear, is due to sympathetic impulses as well as weakening of vagus control. The significance of the supply from the central nervous system is that the heart-beat may be altered to suit the requirements of the body generally. In exertion more blood is wanted in the muscles; in fear the heart automatically prepares for the muscular exertion of fighting or running away.

The rate of the heart beat varies in different animals, and in each animal with the age, being quicker in the young than in the adult. As averages for adult animals the following may be given :—

Horse	30—40	per minute.
Cow	40—50	,,
Sheep	60—80	,,
Man	70—80	,,
Dog	70—120	,,

In a man or a sheep, with the rate of 75 per mniute, each beat will take up 0.8 of a second, of which time 0.4 is occupied with the systole and the remaining half with diastole.

At the height of systole the ventricle comes into contact with the chest wall, giving rise to the so-called APEX BEAT, which may often be seen and can usually be felt at the proper region in each animal. If the ear or a stethoscope be placed on the skin over the heart-region two sounds can be distinctly heard, one during, and one shortly after systole. The second sound is short and sharp, and is due to closure of the semilunar valves; the first sound is duller and more prolonged, and seems to be made up of more than one factor; but closure of the mitral and tricuspid valves and the contraction of the muscle of the ventricle are probably the chief causes.

We are now in a position to trace the circulation in detail, and we may begin with the veins entering the left auricle. These PULMONARY VEINS

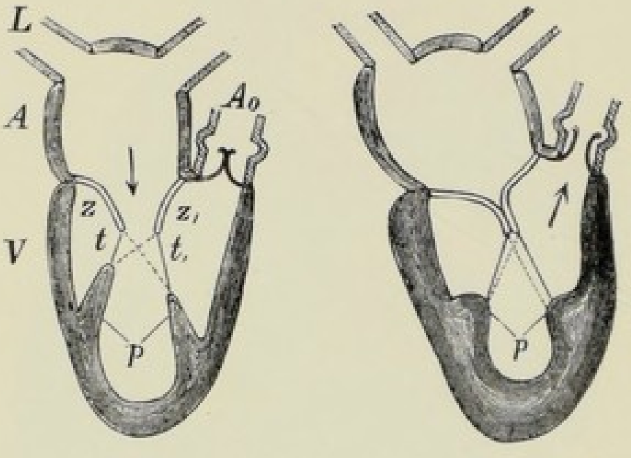

Fig. 51. Diagram to show action of heart valves. A, left auricle; V, left ventricle; Ao, aorta; P, muscular pillars attached to t, chordæ tendineæ; Z Z1, flaps of mitral valve. In the diagram to the left the heart is in diastole; the mitral valve is open and the semilunar is shut. In the diagram to the right, the heart is in systole, the mitral valve is shut whilst the semilunar is open. (After Schultz.)

as they are called, come from the lung and carry bright-red arterial blood in a sluggish stream towards the auricle. The blood enters the auricle, fills it out, and passes through the mitral valve into the ventricle which it distends to a feeble extent, the flaps of the mitral valve floating up so that their edges nearly meet. Then comes the systole. The contraction in the veins has little action, but the quick snap of the auricle empties this chamber, part of the blood passing back into the veins but the main part being driven into the ventricle. Then the ventricle contracts strongly: the walls approach one another and exert pressure on the blood between them. The mitral valve closes tightly, and the *chordæ tendineæ* being pulled on by the muscular pillars to which they are attached not only prevent the mitral valve from being driven into the auricle, but actually pull the whole valve and its attachment down into the ventricle, so that it may be said that the walls on every aspect of the ventricle approach each other in systole. Now out of the left ventricle arises the great artery of the body, the AORTA, and as the blood within it is under pressure the similunar valves are tightly closed. When, however, the pressure in the ventricle exceeds the pressure in the aorta, the semilunar valves open and blood is shot out of the ventricle into the great artery; then the ventricle stops, and at the same instant the semilunar valves close tightly again. From the aorta arise the main arteries for supplying red arterial blood to the whole body. This great vessel soon after leaving the heart forms an arch and then passes lengthwise through the body. In its course it gives off numerous branches. The first branch is a tiny vessel for the heart itself; then come large arteries for the fore limbs and head; then small arteries for the walls of the body cavities; then as the aorta passes through the abdominal region a mighty system leads to the abdominal alimentary canal; then a pair of vessels to the kidneys; then arteries to the pelvic organs, the lower limbs and tail. All these arteries give off branches, and these again divide into smaller branches, and so on until minute ARTERIOLES of microscopic size are formed. As the calibre of each parent branch is less than the sum of the calibres of the smaller branches it gives rise to, the total cross-section of the arterial system gradually increases from the heart to the arterioles, and, in consequence, the rate of the blood stream gradually diminishes. A change in the structure of the walls may also be noted. The aorta and large arteries have walls which are rigid with fibrous tissue and have only a little "give." The smaller arteries have more elastic walls, whilst the arteriole walls are chiefly muscular, the muscles, by their contraction or relaxation, *constricting* or *dilating* the calibre of these vessels.

The blood throughout this arterial system is under pressure, and therefore, as it cannot escape from the aorta back again into the ventricle owing to the semilunar valves, it is forced through the arterioles, which are always more or less constricted, into the smallest vessels of the body or CAPILLARIES which form a dense network round the living cells of the body. The flow of blood in this network of capillaries can be beautifully seen by observing the web of the foot of a living frog under an ordinary microscope. The diameter of a capillary vessel is about that of a red blood-corpuscle; its frail wall is composed of thin and very flat cells, one deep. The flow of blood in the capillaries is slow, the rate being usually given as an inch per minute (though it must be remembered that in no region of the body could the blood pass through more than a small fraction of an inch of capillaries), but its most remarkable character is that the flow is constant and not intermittent and jerky as it is in the arteries. This change is brought about by the elastic character of the arteries, just as the elastic bag in a cosmetic spray-producer changes the intermittent pumping of the air by the hand into a continuous outflow. The blood as it passes through the capillaries alters in character; amongst other changes it loses some oxygen and gains some carbon dioxide, so that it becomes purplish (or venous) in colour.

The blood now leaves the capillaries passing into a number of thin-walled venules, each a little larger than a capillary; these venules unite into small veins and these into larger veins in a branching system resembling the arteries, only that here the current passes from branch to stem and narrows as it travels heartwards. The venous blood from the abdominal alimentary canal, the pancreas and the spleen, passes into the portal vein, as has been stated, and this vein breaks up into branches and these finally into capillaries in the liver so that the blood passing out of the aorta into the abdominal digestive organs has to pass through two systems of capillaries. But from other parts of the body, including the liver itself, the blood passes from twig to branch along the veins until finally it enters into one of two great veins or *venæ cavæ* which open into the right auricle. The veins are thin-walled compared with the arteries, and also very much more distensible. An increase in pressure which would make no apparent increase in an artery might increase tenfold the calibre of a vein. The causes that operate in the flow of blood in the veins are somewhat complex. First there is some back pressure due originally to the heart. Secondly in every movement of the body the muscles during their contraction press on the veins and urge their contents heartwards. This is one of the reasons why exercise is so beneficial and why animals, if they are kept on their feet too long and bereft of natural exercise, show swelling of the veins of the leg or even dropsy. Thirdly there is the suction which is exerted by the chest in breathing. When the thorax expands not only is air drawn into the lung but also blood is drawn towards the thorax along the great veins leading into it. At the same time the midriff or diaphragm compresses the contents of the abdomen and drives heartwards the blood contained therein.

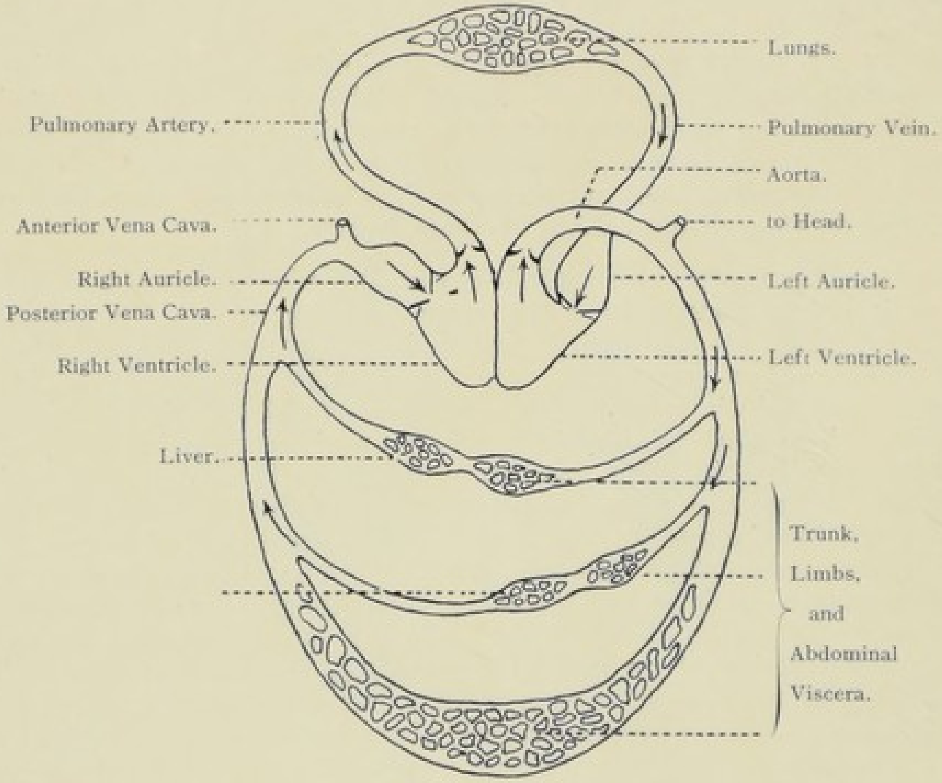

Fig. 52. Diagram of Circulation. (After Halliburton.)

The blood when it reaches the right auricle is subjected to the same cycle as when in the left heart. In the right ventricle however the muscular walls are much thinner and less powerful than in the left, and the artery arising from it, called the PULMONARY ARTERY, has within it a much smaller pressure than in the aorta. The right ventricle contracts at the same time as the left; the tricuspid valve is closed tight and pulled down; a quantity of blood equal to that expelled from the left ventricle is forced into the pulmonary artery; the ventricle stops; the semilunar valves close; and the blood in the pulmonary artery must perforce pass onwards into a series of branches of which the first two into which the artery divides are destined one for each lung. In the same manner as already described a network of capillaries is formed which in this case lines the air cells of the lung. Here a marked change is produced. The blood which has entered the right auricle and ventricle and from this has gone into the pulmonary artery, is venous; here in the lung capillaries it gives off some carbon dioxide and gains oxygen so that it changes its colour from purple to bright red. The capillaries pass into venules and then into veins. The flow of blood through the lung is sluggish, the pressure in the pulmonary artery is small, and as the whole system is inside the thorax the suction of the latter cannot count; but as the lung is continually shrinking and expanding the blood is worked along, aided by back pressure, until it enters the great pulmonary veins and then flows quietly into the left auricle. Thus the double circuit is completed.

The circulation from left ventricle to right auricle is called the GREATER or SYSTEMIC circulation; that from right ventricle to left auricle is called the LESSER or PULMONARY CIRCULATION. The shortest time the blood can take to pass through both circuits is 31 seconds in the horse; this, it must be remembered, is the shortest, not the average time.

A knowledge of this mechanism will explain the following peculiarities of the circulation in, say, a limb—

1. If a ligature be tied very tightly round the base of a limb, both arteries and veins will be compressed, the blood in the limb will be stagnant; none will enter and none will leave. If the ligature be tied less tightly so as to compress the veins and not the arteries, blood will enter the limb, but none will leave, and, in consequence, the limb will swell up and become dropsical.
2. If a vein is cut, blood of a dark colour will well up from the wound in a continuous stream; the bleeding can be stopped by the application of pressure on the side AWAY from the heart. If an artery is cut, the blood will spurt out in bright-red jets that keep time with the heart beats. In this case the bleeding can be stopped by application of pressure on the side *near* the heart.

We have now to investigate the significance of the pressure in the systemic arteries and the changes which it undergoes. That such pressure should exist is due to the fact that the heart is continually pumping blood into the aorta and the elastic arteries, whilst the arterioles, by their constriction, hinder the escape of the blood into the capillaries. It is evident that the arterial pressure will rise—

(*a*) If the force and frequency of the heart beat is increased, the arterioles remaining the same;

(*b*) If the arterioles constrict still further, the heart beat remaining the same;

(*c*) If the force and frequency of the heart is increased, the arterioles at the same time constricting.

The muscles of the arterioles are connected with the central nervous system by two sets of nerves. In the first place fibres from the sympathetic system called *vaso-constrictor* can produce constriction of the arterioles; in the second place there are nerves of uncertain origin which produce temporary paralysis (inhibition) of the muscles and therefore dilatation of the arterioles. These nerves are termed *vaso-dilator*.

Whenever an organ is called upon to act, more blood is required, and this increased flow can be obtained by the simple device of dilating the arterioles in the organ—the blood will flow in greater volume towards the region of lessened resistance. A still greater flow can be obtained if the arterioles in the organ are dilated, and the arterioles in other regions of the body are constricted; whilst an even greater flow can be obtained by these changes in the arterioles combined with an increase in the force and frequency of the heart beat. The proper amount of blood can therefore be regulated to a nicety. If the region requiring the increased blood-flow were a large one, say the muscles of the limbs, then if the arterioles of the muscles were simply dilated the resistance to the blood escaping into the capillaries would be so greatly reduced that the arterial blood-pressure would fall so much in amount that the blood-flow through other regions, and particularly the brain, would almost stop. This is obviated by other arterioles, and especially those in the abdominal region constricting so that the lessened resistance in the muscles is balanced by a greater resistance in the abdominal vessels. This explains why, for instance, digestion of a liberal meal proceeds so badly during violent exercise; the blood is flowing chiefly through the muscles, and a much diminished supply through the digestive organs in the abdominal cavity.

Investigation has proved to what an extraordinary extent the blood pressure is influenced by changes in the arteriolar calibre of the abdominal region; in fact the major changes seem to be conditioned by its state so that the abdominal system has been aptly called the "resistance box" of the circulation. If the constriction of the abdominal arterioles were altogether abolished the blood pressure would fall to such a degree that death would result, even though the arterioles in the muscles and skin were constricted to their utmost. This explains the pallid skin, pinched features and general collapse when inflammatory trouble occurs in the bowel.

The actual pressure in the systemic arteries varies with each animal and to a slight extent with each artery. If a vertical tube were connected with one of the larger arteries of a horse the blood would rise in the tube to the height of about 9 feet and, until clotting occurred, would show oscillations at the same rate as the heart beat. It is the pressure in the arteries which produces the quick jetting of blood which occurs when an artery is cut and which is apt to give a false idea of the rate of flow in the intact artery.

General constriction of the systemic arterioles can be brought about by the following means:—

1. Salts of barium which act directly on the muscles of the arterioles.
2. The drug, or hormone, adrenalin, which acts on the receptive substances of the arteriolar muscles.
3. The drug nicotine (in its first stage of action) which stimulates the nerve cells in the sympathetic ganglia.
4. Venous blood, as occurs in asphyxia, which acts on the nerve cells in the medulla oblongata in the central nervous system, where vaso-constrictor impulses arise.

When general vaso-constriction occurs the resistance to the blood escaping into the capillaries is greatly increased and, if the heart were to beat at the ordinary rate, the arterial pressure would mount up to a dangerous extent. In such circumstances however the vagus centre in the medulla is stimulated and the heart is greatly slowed so that a dangerously high pressure is avoided. Conversely, when the arterioles, are dilated, either generally or only in the abdominal region, as occurs when certain poisons enter the circulation, or if the blood pressure is lowered by extreme hæmorrhage, the heart through the sympathetic system is stimulated to greater activity whilst at the same time the vagus ceases to act.

The arterial pressure in the lesser or pulmonary circuit is low and, as it varies but slightly, and as these variations are dependent on what is happening in the systemic circulation, they possess but little importance.

Pressure in the veins is always low, in fact in the great veins near the heart a negative pressure may exist in which case if the vein wall be cut, air may actually be sucked into the vessel.

When the left ventricle forces its contents into the aorta a pressure wave is started which rapidly spreads through the branching arteries and dies down before it reaches the capillaries. Much the same sort of wave is seen in a long rubber tube in which water is flowing under a little pressure (as in a garden hose). When a blow is struck on the tube near the tap, a wave can be seen running along and the jet from the nozzle can be seen to jump a very short time after the blow is given. This pressure wave in the arteries is called the PULSE and can be felt well whenever an artery is near the skin and has a bony background. The pulse, as felt by the finger, gives one the rate of the heart and the presence or absence of regularity in the heart beat. The initiated can also draw conclusions from the feel of the pulse whether "full" or "thready," &c., though it must be remembered that the veins which accompany the artery have a share in giving rise to what is termed the "volume" of the pulse. The pulse wave is not single in character. Instruments for recording the pulse and frequently the finger alone can detect a second beat just after the crest has passed. This is the DICROTIC WAVE and is produced by the rebound from the semilunar valve when this closes and the ventricle passes into diastole.

The Lymphatic System.

The blood, as it passes through the capillaries, does not come into actual contact with the cells of the various tissues. The capillary, it has been said, has an actual wall. This wall however is so thin that it allows some plasma to leak through forming LYMPH which bathes the cells. The lymph is contained in the loose connective tissue around the cells and all the interchange of nutriment, oxygen, waste products, &c., which takes place between the cells and the blood must be carried out through this medium. When the pressure in the capillaries rises, as occurs in local obstruction of the veins or in local dilation of the arterioles, *e.g.*, inflammation, the amount of lymph increases, and may collect to such an extent that the tissue becomes œdematous or dropsical. There is a very slow circulation of this fluid for it can be shown to pass from the tissue spaces into tiny thin walled vessels which run in clusters, join together, and finally form an easily detected tube running towards the heart and close to the spine. This is the THORACIC DUCT and it empties its contents into a large vein near the heart. In their course the lymphatic vessels enter masses of adenoid tissue called LYMPHATIC GLANDS which are often situated near joints. These glands come into prominence when the lymphatics happen to drain an area where inflammation is going on; they swell up and become painful. Thus an inflamed wound in the human foot will produce swelling of the glands behind the knee and also of those in the groin.

The lacteal vessel in the centre of each villus belongs to the lymphatic system and, as mentioned, its contents pass eventually into the circulation through the thoracic duct.

When a drug or poison is injected subcutaneously it really is forced into lymph spaces, unless by accident it is introduced into a vein, in which case its distribution through the body is rapid. Now, absorption from the lymph spaces can occur in two ways. Firstly, the drug or poison may diffuse into the adjacent capillaries and so reach the general circulation. This occurs more readily the simpler the chemical constitution of the substance. But with substances of extreme chemical complexity, such as proteins, this diffusion is so small as to be practically absent and the only path of absorption open to the substance is to pass in the very tardy

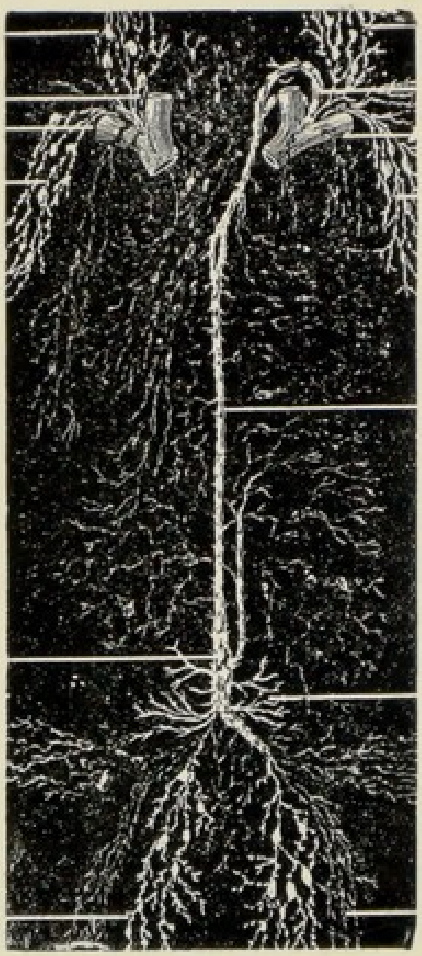

Fig. 53. Diagram of the principal group of lymphatic vessels. (After Quain.)

lymph-stream, through the various glands, into the thoracic duct and so into the general circulation.

The chief factor concerned in the flow of lymph is muscular movement which exerts an intermittent pressure on the vessels, and, as these possess numerous valves all pointing heartwards, the lymph is forced along in that direction. This gives us another beneficial action of exercise.

The peritoneal, pleural and pericardial cavities, and the synovial cavities in joints, may be regarded as potential lymph-spaces in which a minimum of lymph is found in health. When the portal vein is partially obstructed, the amount of lymph which can collect in the abdominal cavity may be estimated by the gallon; whilst collections of fluid in the pleura, pericardial, and synovial cavities are generally the result of inflammatory conditions.

CHAPTER XIII.

Respiration

No physiological activity is so obvious as that rhythm of movement which we call respiration or breathing. The necessity that exists for breathing is made up of a number of factors of which the following are the most important :—

1. The blood as it passes through the lungs takes up a supply of oxygen from the air and gives off some of its carbon-dioxide.

2. The flow of blood towards the heart in the larger veins is facilitated by the squeezing action on the abdomen, and the suction in the chest, which occur during inspiration.

3. In most animals, and particularly those that sweat little, the lungs can get rid of some superfluous heat.

The second and third factors have already been mentioned in previous chapters; the first and most important action will be considered in this chapter.

The Physical Features of Respiration

Air, which is destined to enter the lungs, enters by the nostrils and then through the nasal passages into the pharynx. In yawning or violent breathing air may be admitted by the mouth. From the PHARYNX the air passes through a narrow opening called the GLOTTIS into the LARYNX which latter may be looked upon as the first portion of the wind-pipe. The aperture of the glottis is controllable; it can be completely shut or widened by means of special muscles. The TRACHEA or wind-pipe is a tube kept permanently open by means of incomplete rings of cartilage. The trachea as it enters the thorax divides into two BRONCHI, one for each lung, and these bronchi divide and sub-divide until an immense number of BRONCHIOLES are formed like the twigs on a tree. Each bronchiole ends in a small air-chamber with pouches or alcoves, called AIR-CELLS, around all its sides. In the walls of these air-cells, and separated from the air only by a very thin lining sheet of flat cells, is a dense mesh-work of capillary vessels through which the blood, pumped from the right ventricle, is constantly flowing. Each lung can therefore be looked on as a complex bag sub-divided into a large number of compartments. Thanks to this sub-division the air, which is breathed in, can be brought into contact with an immensely greater number of capillaries than if the bag were a simple one.

The outer surface of each lung is lined by an air-tight sheet of fibrous tissue called PLEURA; the inner surface of the wall of the thorax is similarly lined. Now these pleural surfaces are practically in contact being separated only by a thin layer of lubricating fluid. The lungs are highly elastic, and, in no matter what position the thorax is, are always in a state of stretch. Thus if the chest wall is opened, as may occur through a wound, and air is admitted from outside, or if the lung and its lining of pleura be ruptured so that the air within can escape outwards, the lung on the affected side will, by virtue of its elasticity, collapse, and air will collect between the pleural lining of the lung and that of the chest wall. The lungs it must be remembered contain no muscle so that they are incapable of spontaneous movement. Some of the lower air-breathers such as the frog inflate the lung by forcing air in through a muscular effort in the mouth, akin to swallowing. In all the higher vertebrates however, air is admitted by the device of enclosing the lungs in an air-tight box—the thorax—which latter can be altered in capacity through muscular effort

When the thorax expands the surface of the lung follows the retreating thorax wall and so air is sucked in through the only inlet possible, namely, the trachea. The thorax can be expanded by two methods. Between the

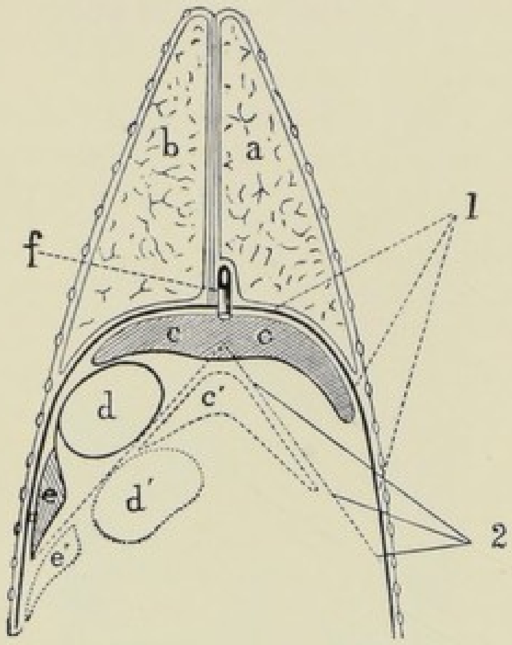

Fig. 54. Horizontal Section of the Horse's Chest, looked at from above, illustrating the Movements of the Diaphragm. (After *Sussdorf.*)

a, right lung; *b*, left lung. 1. Position of the diaphragm during deep expiration; *c*, liver *d*, stomach; *e*, spleen. 2, Position of diaphragm during deep inspiration; *c*′, liver; *d*′, stomach *e*′ spleen; *f*, posterior vena cava as it passes through the diaphragm.

thorax and the abdomen is a dome-shaped sheet of muscle called the midriff or DIAPHRAGM. (Fig. 54). Within the dome are portions of the abdominal viscera, whilst in contact with the convex surface is the heart with a lung on either side. When the muscle, of which the midriff is largely composed, contracts, the dome is flattened particularly at the sides, and thus the thorax increases at the expense of the abdomen. The second method of expanding the thorax is by altering the position of the ribs. This is a complex movement not easily described and best understood by watching one of the larger animals, especially in laboured breathing. The ribs will be seen to move headwards and outwards, increasing the chest girth to a very appreciable extent. The reverse act, namely expiration, when it takes place in quiet breathing, does not demand any muscular effort; all that is required is that the muscular activities producing inspiration should cease. The abdominal contents being under pressure force the diaphragm towards the thorax. Further, the weight and the elasticity of the thorax and the elasticity of lung combine towards the same end, namely, the expulsion of some of the air-content of the lungs. But when breathing is forced or laboured, then expiration must be facilitated and this is accomplished by the muscles of the abdominal wall contracting and therefore pressing the abdominal viscera against the diaphragm. Further, the ribs move in the reverse direction to that which takes place in inspiration and so the capacity of the thorax is reduced.

The amount of air which is taken in (or given out) in quiet breathing has been called "tidal" air but, as no definition of *quiet* breathing can be given, the term is valueless. The maximum volume of air which can be expired after the deepest inspiration possible, is called VITAL CAPACITY. The amount varies in man from 3 to 3.8* litres and is supposed to vary in a horse from 25 to 30 litres. After the most violent expiration there always remains a considerable volume of air in the lungs; this is called RESIDUAL AIR and its volume is given as 1.5 litres for man and 7 to 17 litres for a horse. Once air has been admitted to the lungs it cannot be completely got rid of by mechanical means; in consequence the lungs of a mammal, that has breathed only once, will float in water, whilst the lungs of one still-born, or killed before a breath has been taken, will sink in water.

The Chemistry of Respiration

A clue to what is happening in the lungs is given by the chemical analysis of ordinary air as compared with that of expired air.

Air inspired.		Air expired.
Oxygen 20·9 per cent.	... ...	15·9 per cent.
Nitrogen and Argon 79 per cent.	...	79 per cent.
Carbon-Dioxide 0·04 per cent.	...	4·4 per cent.
Water vapour in varying amount	...	Saturated with water vapour.
Dust and bacteria present ...	...	No dust or bacteria.
		Traces of hydrogen and marsh gas present.

The loss of dust and bacteria is due to the trapping action of the moist surfaces of the breathing passages, particularly those in the nose, but all the other changes we may refer to the lungs. It is evident that oxygen is absorbed and an almost equal amount of carbon-dioxide added to the air. The traces of hydrogen and marsh gas are due to these substances being formed in the bowel by fermentation and being in part absorbed by the blood and liberated in the lungs. The nitrogen it will be observed undergoes no alteration. The main change concerns the oxygen and carbon-dioxide. Now it is found that if blood be placed under an air-pump, gases will escape in quantity sufficient to measure and analyze. The following table furnishes us with the next piece of evidence:—

The air-pump can extract from 100 volumes of blood—

Entering the lungs. (Venous.)		Leaving the lungs. (Arterial.)
Oxygen 13 vols.	... ...	20 vols.
Carbon-Dioxide 46 vols.	...	40 vols.

Plainly, therefore, the blood as it passes through the lungs takes up oxygen and gives off nearly an equal volume of carbon-dioxide. When we next consider how oxygen is held by the blood, we shall find that the hæmoglobin of the corpuscles is responsible for this faculty. If blood be bereft of its corpuscles and shaken with air, 100 volumes of the blood can only hold about half a volume of oxygen, but if the corpuscles are present, about 20 volumes of oxygen. Moreover, a solution of hæmoglobin will act in the same way. One very important character of hæmoglobin is that, if the oxygen of the air, with which it is in contact,

* A litre = 61 cubic inches = $1\frac{3}{4}$ pints.

be lowered from the normal 20.9 per cent. to 13 per cent., the deficit in the oxygen absorbed by the hæmoglobin is trifling; but if the oxygen be still further lowered in a series of equal gradations, then the deficit becomes larger and larger until small differences in the oxygen of the air mean large differences in the amount absorbed. There is nothing very remarkable in this behaviour of hæmoglobin. One can see much the same phenomenon in the absorption of carbon-dioxide by a solution of ordinary washing soda. But to the animal it has a profound significance. It means that the oxygen content of the air can be lowered (either by high altitudes or by dilution with nitrogen) and yet, within certain limits of course, the amount of oxygen absorbed by the blood is little altered. Thus an animal can live in an atmosphere in which a candle cannot burn, provided that poisonous gases are not present; and mountaineers frequently attain to-day to heights of 18,000 feet where the mass of oxygen per unit volume of air is reduced to one-half that at sea-level.

In the lungs the blood does not come into immediate contact with the air, but the oxygen of the latter can readily diffuse through the thin lining of the air-cells and through the capillary wall and into the blood. Through the same membranes the carbon-dioxide of the blood can diffuse outwards. The carbon-dioxide of the blood is held partly in simple solution, partly in the form of bicarbonates. It is also probable that the hæmoglobin can help in carrying some, but a small, portion.

The nitrogen in the blood is simply dissolved and plays no part in the animal economy. Mention must be made here of the poisonous action of carbon-monoxide, a gas which is produced by glowing charcoal and incomplete combustions such as occur when a flame plays on a metal surface, or when dust is roasted by contact with hot metal, &c. This gas has an extraordinary affinity for hæmoglobin and in concentrations of 1 volume per 1,000 volumes of air can oust the greater part of the oxygen from the hæmoglobin. Carbon-monoxide injures or kills not by any specific poisonous action but simply because of oxygen starvation.

Internal Respiration.

Every living cell in the body needs oxygen for combustion purposes either to furnish energy or to remove organic waste. When arterial blood reaches the thin-walled capillaries its oxygen can readily diffuse out into the lymph and so into the living cells where oxidation takes place. Now the chief products of cellular oxidation are water and carbon-dioxide both of which diffuse out of the cell into the blood. Hence arterial blood passing through the capillaries becomes venous, that is, loses some oxygen and gains almost as much carbon-dioxide. The more active the cell, the more oxygen does it require and the more carbon-dioxide does it pour out.

Respiratory Exchange.

The amount of oxygen absorbed, and conversely, of carbon-dioxide given out, varies within wide limits according to the size of the animal and to the activity of oxidation in the animal's tissues. The following table gives an idea of the respiratory exchange in a state of rest of a number of animals for 24 hours:—

Animal.	Weight.	Oxygen absorbed.	Carbon-dioxide given out
Horse	500 kg*	2,630 litres	2,530 litres
Boy	56 "	371 "	296 "
Sheep	50 "	360 "	327 "
Dog	30 "	252 "	205 "

* kg = Kilogramme = 2·2 pounds

But in the same animal the amounts may be greatly increased by exercise. Thus, a horse weighing 450kg. has been found to give the following figures :—

Oxygen absorbed per minute.		Carbon-dioxide given out per min ut
Rest	1·7 litres	1·6 litres
Ordinary work	15·7 "	13.7 "
Heavy work	29·3 "	28 "

Further, when the animal is exposed to cold greater than can be combatted by cutting down the heat loss, the proper temperature is maintained by an increased oxidation in the body and thus again the respiratory exchange is increased. The respiratory exchange is also to some extent dependent on the amount of food. An increase in nutritive material absorbed is always accompanied by increased oxidation and production of carbon-dioxide.

The Regulation of Respiration

The muscles concerned in respiration receive rhythmic impulses from their respective nerves which latter arise from the central nervous system and chiefly from the spinal cord. Thus if the *phrenic* nerve in the neck be cut, the diaphragm is thrown out of action and inspiration must be carried out by the thorax alone. It has been found by experimental investigation that a collection of nerve cells in the *medulla oblongata* is specially connected with the nerves to the respiratory muscles and is also in communication with a number of afferent or sensory paths and particularly those in the vagus (10th cranial) nerve. This collection of nerve cells is concerned with the regulation of respiration and it has been called the RESPIRATORY CENTRE. When these cells are excited, impulses pass down the appropriate nerves and the respiration increases in rate or depth or what is more common in both together and the *ventilation* of the lungs is hereby increased. The respiratory centre can be excited in a number of ways—

1. By carbon-dioxide brought by the blood. As has been shown the red blood leaving the lungs still contains carbon-dioxide and it has been found that this amount, when the animal is at rest, is just sufficient to excite the centre to produce quiet breathing. If a man takes several deep breaths then the breathing may be stopped for a longer period than could normally be borne. This condition is due to the fact that the deep breathing removes more carbon-dioxide than usual and not until this gas has mounted up to a certain concentration will the centre act. When an animal is vigorously exercised the breathing gets laboured. This again is largely due to the increase to the carbon-dioxide in the blood. We have here a beautiful automatic mechanism whereby the carbon-dioxide in arterial blood can be kept almost constant. Even a trifling rise in the carbon-dioxide content of the blood brings about a big increase in lung ventilation and in consequence the gas can be got rid of at a quicker rate.

2. Low oxygen content of the blood. If an animal breathes air containing less than 13 per cent. of oxygen the deficit in the blood excites the centre and respiration is quickened and deepened. Thus animals at an altitude of 12,000 feet and over display a marked increase in the amplitude of respiration. In strangulation the violent respiratory efforts which are made are produced not only by oxygen deficiency but by the heaping up of carbon-dioxide.

3. When the temperature of the blood rises above the normal the respiratory centre is excited, particularly in the non-sweating animals. The excitation, however, is never so intense as that due to either of the forementioned factors.

4. There is some evidence that in very violent exertion and in asphyxia such as occurs in strangulation, drowning, &c., the centre is excited, not only by carbon-dioxide excess and oxygen loss, but also by the entry into the blood of waste products from the muscles which would under normal conditions be oxidised.

The centre can be influenced by nervous channels as well, witness the limited voluntary control of the higher brain over the respiratory movements. Then there is also the action of the vagus to consider. When the lung is inflated and stretched the vagus sends up messages which stop further inspiration; when the lung is partly deflated, and the stretch somewhat relieved, the vagus sends up messages which start inspiration. The vagus mechanism is therefore for regulating the rhythm of the respiratory centre.

Respiration Hygiene

If the air be too dry the mucous membranes are liable to suffer, if too moist the temperature regulation of the body is impeded. Rarely does the oxygen of a badly ventilated house or stable or pen fall to an extent that would be harmful. But the carbon-dioxide of the air should not be allowed to mount up. In the case of the human being, house-ventilation aims at 0.06 per cent. as the maximum, and the same figure may be given for the domestic animals. When animals are herded too closely together in a building a number of harmful factors are produced. The air is rendered too moist and too warm; the carbon-dioxide is increased in percentage; poisonous gases voided from the intestine are breathed; moreover the warm moist air allows bacteria to grow luxuriantly on the *débris* of the body (sweat, shed cuticle, and, in the case of the lower animals, ordure) and so poisonous products of putrefaction are added to the air. The opportunity given to infectious diseases to spread where overcrowding exists is obvious.

CHAPTER XIV.

Renal Excretion.

The functions of the kidneys may be epitomised as follows :—

1. Waste matter and foreign or harmful substances are removed from the blood.

2. The blood is kept neutral in reaction. If it tends to get acid the kidney removes the acid excess, if alkaline then the alkali excess is eliminated.

3. The blood is standardized as to the concentration and relative proportions of its salts. As has been stated in the chapter on blood, not only the total amount but the proportion between the individual salts in the blood remains constant. As, however, the supply of salts in the food is very variable, some adjustment is necessary and this we find in the kidney.

The Mechanism of Renal Excretion.

The artery entering the kidney divides and subdivides until there are formed thin, straight arterioles which radiate from within outwards. Arising from these straight vessels and almost at right angles with them are a number of smaller arterioles. These finer arterioles then form peculiar structures just visible to the naked eye—the GLOMERULI. These in reality are produced by each fine arteriole being wound on itself to form a convoluted tuft like a tangle in a cord. Wrapped closely around the glomerulus is a double-walled capsule with an opening in it (Fig. 55).

Fig. 55. Diagram showing straight arteriole, *a*; glomerulus, *m*; capsule, *f*; capillary plexus, *e'*; and tortuous tube, *t*. (After *Bowman*.)

A good picture of the shape of the glomerulus can be obtained by imagining a piece of thin rubber tubing folded into a knot or a bunch whilst around this is closely applied a collapsed rubber balloon. Now the function of the glomerulus is to act as a filter. The blood enters the glomerulus under the pressure given it by the pumping heart and, as there is some resistance to the outflow, it is forced not only through the capillary wall but also into the adjacent wall of the capsule. A filtrate, therefore, collects in the space between the two walls of the capsule. Now the membrane of which the capsule is composed is such that water and the salts of blood, and presumably also urea, can pass through, but the other constituents, with the corpuscles, are held back and remain in the blood stream. Such a filter as this is not unknown in physical science. A clay cell soaked in hot gelatine solution and then allowed to cool, so that the gelatine sets in the pores, can be used as a filter, allowing water and the simple constituents present in blood to pass through, but retaining the corpuscles and albumens and other complex constituents. In the capsule, therefore, there collects a watery filtrate from the blood: this escapes from the opening mentioned above and travels down a tortuous tube and finally, being collected in special ducts, is poured out as urine into the pelvis of the kidney. But a great change occurs in the fluid as it passes through the tortuous or "convoluted" tube. The blood which has been concentrated and which has lost some of its dissolved constituents in the glomerulus leaves the latter by a small vessel and then flows in a network of capillaries which embraces the convoluted tube. Here a good part of the water and some of the salts are re-absorbed back into the blood; but typical urinary constituents are left alone. The lining cells of the tortuous tube also have the power of picking out from the blood certain urinary ingredients such as the pigments or foreign substances which have not passed through the glomerular membrane, and of adding these to the urine within. Even hæmoglobin which has escaped from corpuscles, when these are diseased or in any way broken up, is treated as a foreign body and is thrown out into the urinary stream. The cells also of the tortuous tube have also the faculty of standardizing the blood as to reaction and salt content. The blood finally leaves the meshwork of the capillaries purified and standardized whilst the fluid in the tortuous tube is now ordinary urine and is ejected as such. The kidney contains many thousand glomeruli with their attendant tortuous tubes and plexus systems.

It will be evident from the above statements that the flow of urine will be increased—

1. If the blood pressure be raised;

2. If the kidney vessels are dilated admitting more blood to the glomeruli and at higher pressure; this occurs with drugs like turpentine and caffeine;

3. If absorption in the tortuous tubes is hindered; this occurs after administration of sulphates;

4. If the blood be watery as occurs after copious drinking unaccompanied by heavy sweating.

The converse of these will reduce the flow of urine.

The urine collected in the pelvis of the kidney flows along a tube called the URETER being driven by peristaltic contractions. Each ureter enters the bladder so obliquely that a valve is formed effectually preventing any back-flow. The bladder is a hollow organ well supplied with elastic tissue and smooth muscle in its walls. Its nerve supply and its capacity relative to the animal's size, vary with different species and are connected with the animal's habits. Thus the ox can void urine while walking, the horse as a rule only when stationary, whilst the carnivore, being a hunting animal, is fitted with an unusually capacious bladder and one more under voluntary control, so that it can stalk its prey without betraying its presence by passing urine. The expulsion of urine from the bladder through the urethra is a reflex action excited by tension of the bladder wall or irritation of the mucous membrane. It can be started or stopped by voluntary effort. The nerve centre for this reflex lies in the lower spinal cord.

The Urine

The amount passed *per diem* varies with the age and species and in each animal with the quantity of fluid drunk and inversely as the amount of evaporation from the skin and lungs. The following table gives an idea of the amount passed in twenty-four hours :—

Ox	10 to 25 litres*
Horse	5 to 8 ,,
Pig	1·5 to 8 ,,
Small ruminants	1 to 5 ,,
Man	about 1·5 ,,
Dog	0·5 to 3 ,,
Cat	about 0·3 ,,

Certain chemical substances are important constituents of the urine of all mammals :—

1. Urea, a nitrogenous body containing also carbon, hydrogen and oxygen. If urine be concentrated by evaporation, cooled and treated with nitric acid, a rich deposit of flaky crystals of urea nitrate is formed. Urea is readily attacked by bacteria if urine be exposed to air, and is changed into ammonium carbonate—hence the ammoniacal odour of stables, &c. Urea is derived from protein and the amount excreted in a day varies parallel with the amount of protein eaten. It represents the protein used as energy supply rather than that used for repair.

2. Purin bodies including Uric Acid. These are substances containing the same elements as urea but they are more complex in constitution. They are derived partly from the nucleo-proteins of food and partly from the activity of the nuclei of not only the fixed tissues but also of the white cells of the blood. Uric acid is found in small quantities in herbivores; generally speaking it varies directly with the amount of protein eaten.

3. Kreatinin—containing the same elements as urea but closely allied to a constituent of muscle. Some physiologists regard it as the decomposition product of protein used for muscle repair.

4. Pigments—these which give the characteristic colour to urine are really altered bile pigments which have been absorbed from the gut.

5. Sulphates. Proteins contain sulphur which, in the body, is oxidised to sulphuric acid and leaves the body in the form of sulphates of sodium, potassium, magnesium and calcium.

6. Chlorides of Sodium, Potassium, &c. These are salts of the food and of the blood and are continually being excreted in the urine.

7. Ammonia—fresh urine contains small quantities of this substance probably formed by the spontaneous decomposition of urea.

Striking differences can be observed between the urine of herbivores on the one hand and that of carnivores, of omnivores in whose food protein preponderates, and of all young mammals living exclusively on milk. The urine of the carnivores, etc., is acid in reaction, is transparent and contains little or no sediment. It also contains phosphates of the four physiological metals in considerable amount and its content of sodium is generally greater than that of potassium. Uric acid is also present in appreciable quantity but aromatic bodies and oxalic acid are found only in traces. Such urine may occasionally show a sediment of uric acid and when, on standing, it becomes alkaline in reaction, phosphates are thrown out of solution as cloudy precipitates. The urine of the herbivores on the other hand is alkaline and turbid. The solid matter held in suspension consists chiefly of carbonates of lime and magnesia so that the urine effervesces on

* A litre = 1¾ pints.

adding acid. Oxalate of lime is also present in the form of minute crystals. Phosphates are present in very small quantities, these substances in herbivores being excreted mainly by the bowel. Potassium is generally in excess of sodium. Hippuric acid and aromatic bodies, including carbolic acid and pyrocatechin, are present in appreciable quantities. The urine of herbivores when placed in a glass vessel will be found to darken from the surface downwards just as a photographic developer will do; in fact some aromatic bodies present in herbivore urine can actually be used for developing photographs! The relatively large quantities of oxalic acid and aromatic bodies are due to the presence of these substances pre-formed in the food; thus a horse fed on meadow-hay will excrete three times as much hippuric acid as one fed chiefly on oats.

It is interesting to note that, when a herbivorous animal is allowed to starve, its urine becomes similar to that of a carnivore. This is due to the fact that the starving animal lives on its own tissues and is therefore in all truth a carnivore.

The number of waste products and of foreign substances, inert or poisonous, that appear in the urine is very large and no useful purpose could be served by attempting to name them here. Not a year passes but some new ingredient of urine is discovered; but the substances named above constitute by far the greater portion of the solid matter present.

The following table gives an idea of the composition of human urine taking this as a type:—

Quantity in 24 hours	1,500	ccs.*
Urea	30.0	grms.
Uric acid	0·7	,,
Kreatinin	1·0	,,
Hippuric acid	0·7	,,
Other organic matter	2·6	,,
Total organic matter	35.0	,,
Sodium chloride	15.0	,,
Phosphoric acid	2·5	,,
Potassium	3·3	,,
Other mineral matter	4·2	,,
Total mineral matter	25.0	,,
Total solids	60.0	,,

In the healthy animal neither blood nor hæmoglobin should be present in the urine. If such appear it means disease or accident, or poisoning by such substances as pine-needles, fox-glove, spurge, &c. Sugar in health is present only in the minutest traces. Albumen is absent, though in most mammals the urine may contain some slimy mucin or nucleo-protein derived from the urinary tracts—bladder and urethra chiefly. Bile appears in the urine in certain diseases such as jaundice.

* 1,000 cc. = 1 litre. 1 gram = 15·4 grains.

CHAPTER XV.

The Afferent Systems

In Chapter III. it was stated that all nerve impulses entering the nervous system start in definite end-organs or receptors which are specially attuned to some particular form of stimulus. The various receptors of the body present certain broad outlines of similarity which may be given as follows:—

1. Each receptor is readily responsive to one particular form of stimulus and responsive with difficulty to all other forms.

2. If a receptor, or the nerve coming from it, be excited by any form of stimulation, the same sensation is always experienced.

3. A certain intensity of stimulus is necessary with each receptor before it can start a nerve impulse. If the stimulus be increased a limit is reached at which no further increase of sensation can be produced by increasing the stimulus. Between these limits sensations vary in intensity according to the proportion that exists between the stimuli.

4. Each type of receptor can readily be fatigued by its particular stimulus, especially when this is intense.

The receptors of the body can be classified as follows:—

PROPRIOCEPTORS.—These are receptors which are set in action by stimuli caused by the animal's movement or position. Impulses arising from them give information as to the position of different parts of the body,

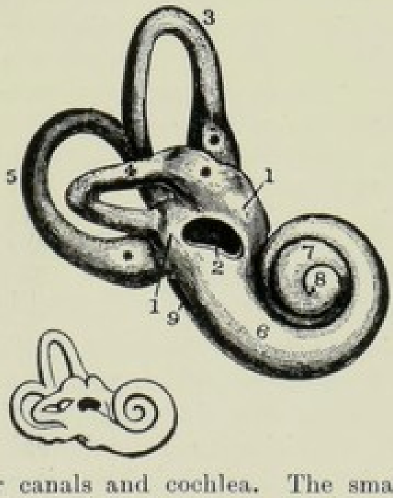

Fig. 56. Semi-circular canals and cochlea. The smaller figure shows the natural size in man. 3, 4 and 5 the semi-circular canals; 6, 7 and 8 the cochlea. 2, elastic window leading to *scala vestibuli*; 9, elastic window leading to *scala tympani*. (After Sömmering.)

the extent of movement and the resistance to muscular action. These receptors are found in muscles, tendons and ligaments (see Chapter III.) and are probably excited by strain in these tissues. They are also present in joints being here responsive to pressure and movement. In the head, and associated with the internal ear, we find on each side a proprioceptive organ, the labyrinth or semi-circular canal system, which possesses a very signal importance (Fig. 56). The leading feature in each labyrinth is the presence of three bony tubes each curved so as to form an arch and communicating with a common reservoir at its base. One arch lies on the flat, that is, in the horizontal plane, whilst the other two are vertical, one running in a fore and aft direction and the other in a side to side direction. Within these tubes is a watery fluid into which dips, in each tube, a brush of fine filamental receptors. Held in suspension in the fluid are certain fine particles of solid matter like sand-grains. Now, in whatever position the head is placed, the solid grains will gravitate in a particular direction, and if the head be moved the fluid by inertia will circulate in a definite manner. It is thus that an animal attains its knowledge of head position and movement. If, in a pigeon, the horizontal arches are destroyed, the bird apparently loses all sense of movement in a horizontal plane and allows its head to wag from side to side. The labyrinth also supplies the requisite information for maintaining a definite posture and for preserving balance. It is to the presence of the labyrinth that we may ascribe that great expansion of the central nervous system called the cerebellum, for it is here that the impulses, continually received from the labyrinth, are co-ordinated and dispatched to other regions of the central nervous system concerned with muscular innervation.

INTEROCEPTORS.—These are found in the lining of the alimentary tube and are concerned with food. In the mouth, and particularly at the back of the tongue, are taste receptors. These respond to various chemical bodies when in solution and give rise to the sensations of sweet, bitter, saline, acid and alkaline. It must be remembered that the majority of the sensations loosely called tastes are really flavours and are detected by the nose which is in communication with the back of the mouth. The sensations of thirst, hunger and satiety are probably referable to receptors in the mucous membrane of the alimentary canal from the pharynx to the stomach.

SKIN-RECEPTORS.—These give the animal cognisance of contact and of the incidence of heat. Scattered irregularly over an area that involves the entire skin and dips, for a short distance, into the mucous membrane of the canals opening on the skin, are receptors that are sensitive to rise of temperature, others to fall of temperature, and others to distortion of the skin (touch). Many hairs are attached at their roots to receptors and owing to the leverage which they exert can give rise to a sensation even on the most delicate displacement.

TELERECEPTORS.—These are receptors which give cognisance of changes in the outside world at some distance from the animal. To them are due the faculties of seeing, hearing and smelling.

1. THE EYE.—This organ may be roughly likened to a photographic camera. It possesses a lens system which focusses a picture of the outside world (when illuminated) on a sensitive surface—the retina—in which are placed receptors specially sensitive to the ethereal disturbances known as light. The structure of the eye is in brief detail as follows (Fig 57). In front is a transparent convex sheet of tissue called the CORNEA which is inserted, like the crystal of a watch, into the very tough white tissue called the SCLEROTIC which constitutes the major portion of the shell of the eyeball. The cornea is well supplied with pain receptors and probably with these alone. It is kept moist, and its surface smooth and free from foreign matter, by the rhythmic wiping action of the upper eyelid, or in some animals by the transversely moving nictitating membrane, the under surfaces of which are kept lubricated by a secretion formed in a special gland

—the lachrymal or tear gland. Painful sensations arising from the cornea give rise reflexly to closure of the lids and copious secretion of tears. The cornea, it may be observed, possesses no blood vessels. Covering the sclerotic in front (*i.e.*, the white of the eye) is a thin sheet allied to the mucous membranes called the CONJUNCTIVA. This is reflected on to the under surface of the lids and is richly supplied with blood vessels which are capable of wide alterations in diameter. The curvature of the cornea is not regular; it resembles more the bowl of a spoon than the surface of a sphere. The direction of the different curvatures varies in different animals. Within the dome of the cornea is a watery transparent fluid—the AQUEOUS HUMOUR. This fluid is under some pressure and so maintains the convexity of the cornea and separates this from the next structure to be mentioned. Floating in the hindmost region of the aqueous humour is a perforated curtain or diaphragm called the IRIS. The iris in all animals (except

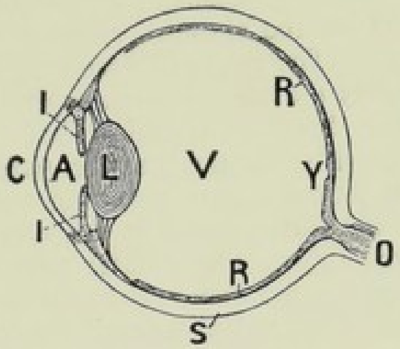

Fig. 57. The Eye.—C, cornea; A, aqueous humour; I, iris; L, crystalline lens; V, vitreous humour; R, retina; S, sclerotic; O, optic nerve.

albinos) is deeply pigmented and is opaque to light. It contains muscular fibres, disposed radially and circularly, which by their contraction can widen or narrow the central aperture called the PUPIL. The iris is plentifully supplied with blood vessels, and by two sets of nerves, a cranial autonomic supply, from the third cranial nerve, which constricts the pupil, and fibres from the thoracic autonomic which dilate the pupil. The use of the iris is twofold; it can regulate the amount of light entering the eye and thus shield the delicate receptors within from injury through excess of light, and secondly, when the illumination is sufficient, it can help in forming a clearer retinal image of the outside world by shutting off all rays of light except a narrow central beam—an action which will be familiar at once to all who have had anything to do with photography. The iris works reflexly, that is, automatically. When the retina is in darkness or is feebly illuminated, the pupil is widely dilated; if the light entering the eye increases in intensity the pupil constricts correspondingly. The shape of the constricted pupil varies with different animals, being circular in man and the dog; slightly oval in the rabbit; having the form of a slit which is vertical in the cat, but horizontal in most of the domestic animals. The iris responds to drug treatment giving a dilated pupil with atropine, cocaine and adrenalin and in the latter stages of chloroform anæsthesia, but a narrow pupil with eserine, and opium and in the earlier stages of chloroform anæsthesia. It also varies to some extent with the blood-pressure and the state of the emotions, *e.g.*, fright. The movements of the iris serve this additional purpose that they act as a circulating agency on the fluids within the eyeball. Immediately behind the iris is the CRYSTALLINE LENS which is composed of transparent laminæ devoid of blood vessels and nerves and arranged like the layers in an onion. The lens is highly elastic and is attached firmly along its border to a sheet of tissue called the CHOROID which sweeps round a great part of the eyeball beneath the sclerotic. The mechanism of focussing for near and far objects in some of the lower vertebrates is carried out in much the same way as in a camera, namely, by moving the lens forwards or backwards. But in mammals this device is supplanted by another, namely, an alteration in the lens itself. When a mammal has its eye focussed for far distance that is, in the resting position, the lens is kept on the stretch by the purely physical character of its attachments to the choroid. As this stretch is exerted all round, the lens is kept flattened, particularly in its front aspect. When however focussing for near objects is desired, a special muscle called the CILIARY MUSCLE, which lies along the root of the iris, pulls on the choroid and draws it forward so that the tension on the lens is relieved and the lens, by virtue of its inherent elasticity, bulges, particularly on its front surface, becomes therefore more convex as a whole or, in ordinary parlance, becomes a stronger lens. This explains why focussing for near objects is recognised by us as requiring effort; when focussing for far objects we stop the action of the ciliary muscle and let the choroid, through its greater elastic pull, drag upon the lens margin. The range of focussing in the domestic animals is not nearly so wide nor is the mechanism as perfect as it is in man and the monkey. Behind the lens is a glairy but transparent fluid, the VITREOUS HUMOUR which fills up the greater part of the eyeball. In contact with the vitreous humour and sweeping round the inner wall of the eyeball as far as the lens attachment, is the very delicate RETINA which contains the receptors for light. The greater part of the retina does not belong at all to the peripheral nervous system; it is in reality a protrusion of the brain stem; the so-called optic "nerve" (second cranial nerve) which can be seen entering the eyeball and spreading out into the retina, being not a nerve trunk but a column of white matter belonging to the central nervous system. One of the many layers of the retina does however belong to the peripheral nervous system and this is the layer of "rods and cones" which consists of a mosaic of receptors for light attached each to an afferent neuron. At that point in the retina where the optic "nerve" with its attendant blood vessels enters, the layer of light-receptors is absent and so we have the well-known blind spot. In many portions of the retina the layer of rods and cones does not present an unbroken surface to the light, being traversed by blood vessels and nerve fibres, but in the centre and almost in a line with the pupil and the centre of the lens, the layer of receptors is free from superimposed blood vessels and on it the light can fall without any interruption.

The range of ether rhythms (red to violet) to which the retina is responsive is limited and is very small in comparison with the range of the air rhythms which can be perceived by the ear as sound. The mechanism by which colour is appreciated is not understood. According to one theory there are receptors for the three fundamental colours, red, green and violet, any intermediate colour being perceived by the unequal stimulation of two or all three of these. According to another theory certain colours including white, provoke chemical disintegration within certain receptors whilst other colours including black excite chemical building up in the same receptors. Vision, it may be stated, presents a number of curious features such as *contrast phenomena, after images,* &c. in fact no sense organ can be so easily tricked as the eye. One important faculty which has a distinct significance is the power of the retina to adapt itself to feeble illuminations, being able, after a certain interval, to see with fair distinctiveness, objects which were at first hidden in darkness. Behind the retina in most domestic animals is a glistening coat, the TAPETUM, which reflects light and gives to the eyes of these animals a peculiar glare in low illuminations.

The eyes of all mammals present certain optical defects.

1. The system is not properly centred, that is, the centres of the cornea, the pupil, the lens and the retina do not lie in a straight line.

2. The curvature of the cornea, as also that of the lens, is not regular. Such a departure from the purely spherical means a distortion of the image on the retina. This defect is present in all eyes and is very marked in those of the lower animals whose vision must be far from perfect. To it the name *astigmatism* has been given.

3. A very common failing is *myopia*, or short-sightedness, due to the fact that the distance from the lens to the retina is too great and in consequence the image of a far object is focussed in front of the retina. This defect can be partly remedied in the human being by wearing concave glasses. It is very common in the lower animals and is often associated with marked astigmatism.

4. In *hypermetropia* the lens is too near the retina and objects at a distance require some focussing effort, whilst near objects cannot be seen clearly at all or only so by a violent action of the ciliary muscle. This is remedied in the human eye by wearing convex lenses.

The eyeball can move in its socket to a limited extent. Four small muscles, called *recti*, are attached to the outer surface of the sclerotic and, by their contraction, can turn the eyeball so that the cornea looks up, or down, or backwards, or forwards (outwards or inwards in man), or a combination of two of these. The eyeball can be rotated to a slight degree in a direction with or against the hands of a watch by two other small muscles called the *superior* and *inferior oblique;* by this movement the pupil can remain horizontal in whatever position the head is. Slight protrusion and retraction of the eyeball from the socket can occur in most animals through special muscles innervated by the thoracic autonomic.

II. THE EAR.—The ear in many respects is a mechanism superior to the eye. Owing to the qualities of the air-waves to which it responds the ear need not be directed towards the source of the sound. Moreover it has a greater analytic power, being able to distinguish two notes when sounding together, and has the faculty of recognising noises as well as musical tones. The external ear has some slight action in collecting the sound waves and in partially shielding the ear from all sounds except those to which the attention is directed. The sound waves enter the curved canal called the EXTERNAL AUDITORY MEATUS and then strike against a thin membrane, called the EAR DRUM, which completely separates the meatus from a chamber within called the TYMPANIC CAVITY. The ear drum is set in movement by the sound waves in much the same manner as the disc in a telephone receiver. To the inner or tympanic aspect of the drum is attached one end of a bridge consisting of three small bones (ossicles) which stretches across the tympanic cavity and conveys the vibrations of the drum to the wall on the opposite side. The tympanic cavity contains air which is in communication with the air in the upper part of the pharynx by means of a special air-pipe—the Eustachian tube. This tube, however, opens only in the act of swallowing or yawning, but sufficiently often to equalise the pressure within and without the tympanic cavity and so to prevent the drum from being sucked inwards or bellied outwards. The actual organ of hearing is the COCHLEA, which is a bony structure bearing a striking resemblance to a snail's shell (Fig. 56). The spiral cavity however is not single as in the shell but divided, except at the extreme tip, by two partitions into three spiral canals—the *scala tympani*, the *scala vestibuli*, and the *canalis cochleæ* (Fig. 58). All these canals are filled with a watery fluid. The upper partition—Reissner's membrane—is very flimsy, but the lower one is made up of a strong shelf of bone from which a membrane—the BASILAR MEMBRANE—stretches to the opposite wall. This basilar membrane is composed of straight fibres which radiate out from the tip of the bony shelf. Perched on the basilar membrane, and continuing with it up the whorl, is the ORGAN OF CORTI of which no detailed description need be given here as so far its method of action has not been fully elucidated. It will be enough to state that the auditory nerve has its endings in the organ of Corti, which latter may be looked on as an array of sound-receptors.

The vibrations of the ear drum are communicated to the bridge of ossicles described above. The other end of the bridge is fastened to an elastic window (Fig 56, 2) that shuts off the *scala vestibuli* from the tympanic cavity and so the vibrations are transmitted through this elastic window to the fluid in the *scala vestibuli*. The vibrations pass up this canal to the tip of the cochlea and then down the *scala tympani* and come to a halt at another elastic window which shuts off the lower end of the *scala tympani* (Fig. 56, 9). The vibrations therefore course above and below the

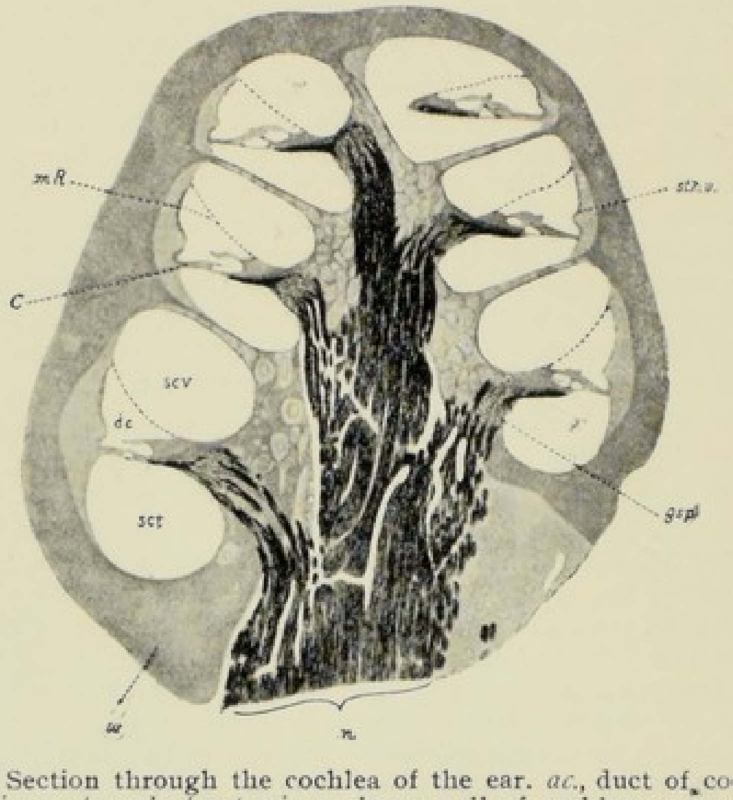

Fig. 58. Section through the cochlea of the ear. *ac.*, duct of cochlea; *sc v*, *scala vestibuli*; *sc. t*. *scala tympani*; *w*, bony wall of cochlea; *c*, organ of Corti on *membrana basilaris*; *m.r.*, membrane of Reissner; *n.*, nerve fibres of cochlear nerve. (After Sobotta.)

canalis cochleæ and set the fluid in this receptacle moving. The basilar membrane is affected by the movement and so causes a distortion of the organ of Corti and this causes stimulation of the sound-receptors.

The intimate connection that exists between the organ of hearing and the semi-circular canal system must serve some purpose but what it is has not as yet been discovered.

III. SMELL. The sense of smell is in so many ways connected with the selection of food that it is often classed with interoceptive sensations; but with the majority of animals other activities are guided by it. Thus the presence of enemies can be revealed; offspring can be recognised, and traced if strayed; vitiated air can often be recognised as such; whilst in the sexual life of most animals it plays a very important part. In man the delicacy of the sense of smell is greatly inferior to that existing in most other mammals, a decadence that may be due to the elevation of the head through the assumption of the erect posture. Yet even as it exists in man the sense of smell is many times more delicate, as a qualitative test, than the most refined methods of spectrum analysis. The receptors for smell are placed in a small yellowish patch of mucous membrane in each nasal passage. The fine afferent nerve fibres pass through the ethmoid bone into the skull and enter a special protrusion of the central nervous system called the olfactory bulb. The so-called olfactory "nerve" on each side (first cranial) is, like the optic nerve, a strand of white matter belonging to the brain stem. Substances which are perceived by the sense of smell are carried in the air in the form of gases, more rarely as matter in a finely divided state, and are first dissolved by the moisture covering the receptor patch of mucous membrane before the sensation is evoked.

PAIN RECEPTORS.—It is a matter of doubt whether a definite apparatus is necessary to start nerve impulses classified as painful. Some physiologists consider that a naked nerve-ending is sufficient. The significance of pain is that, at the spot where the impulses are inaugurated, the integrity of the living tissue is threatened by some destructive agency, such as extreme heat, cold or pressure, wounds, chemical corrosives, &c., on the skin; distension in the gut and heart, and inflammation in every region endowed with pain nerves. The receptors, or nerve endings, are constructed so as to respond to the change before the tissue is seriously impaired; the attention can therefore be directed to the abnormal part and an effort be made to remove the threatening agent, or to avoid further injury. Pain acts therefore like an alarm mechanism giving urgent warning that danger threatens and is indeed a most beneficent provision of nature. The skin and cornea are very rich in pain receptors which are frequently in action; the alimentary and muscular receptors are occasionally active, whilst those in the heart and other viscera may never start an impulse throughout a whole life-time. The regions of the body devoid of pain receptors are very few in number; those that may be mentioned are the outer layer of the skin, cartilage, the retina, and the central parts of the liver.

Visceral sensations not classifiable under the above headings arise in the urinary, genital and pulmonary organs. They are concerned with special functions of these organs when such are under any voluntary control.

CHAPTER XVI.

The Central Nervous System

The central nervous system is composed of a vast number of neurons collected together and forming a column or cord with two pairs of special expansions. The greater part of this column is composed of the SPINAL CORD which lies in a bony arch in the spine. This portion continued into the skull constitutes first the MEDULLA OBLONGATA, then the PONS, then the region of the CORPORA QUADRIGEMINA, and then the region of the THALAMUS. One paired expansion arises from the pons and is called the CEREBELLUM, the other paired expansion arises from the top of the column and forms the CEREBRUM, or brain proper, a portion of the central nervous system which is relatively very small in the lower vertebrates but, in the mammal, fills up the greater part of the cavity of the skull. That portion of the column which lies within the skull, namely from the thalamus to the medulla inclusive, is frequently termed the BRAIN-STEM.

A striking feature of the central nervous system is the large number of nerve cells present which, when massed together, constitute with their smaller processes what is termed *grey matter*. Intermingled with the nerve cells and their processes in the grey matter is a frame-work of cells called neuroglia. The axons arising from the cells in the grey matter when invested with insulating sheaths tend to run in strands and constitute what is termed *white matter*. But the majority of the processes of the nerve cells do not possess this sheath and do not extend beyond the limits of the grey matter. The sheathed axons of the white matter closely resemble the nerve fibres of the peripheral nervous system; they differ however from these in not possessing the external sheath or neurilemma, and, probably owing to this deficiency, cannot regenerate when injured. White matter is also devoid of the framework of connective tissue which gives a characteristic toughness to nerve trunks; in consequence it is soft and pulpy and the constituent fibres are more easily ruptured. In the chapter on nerve it was stated that the cells of the afferent and post-ganglionic neurons were all external to the central nervous system whilst those of the motor and preganglionic neurons lay within the central nervous system. But these latter constitute only a minute fraction of the total number of cells in the grey matter. By far the greater number of the neurons of the central nervous system are connecting neurons allowing impulses to pass from one portion of the C.N.S. to another and forming so many junctions, by means of synapses, that each afferent neuron is placed in physiological connection with every motor and preganglionic neuron and probably with every cell in the whole central nervous system.

THE SPINAL CORD.—In this portion of the central nervous system the grey matter forms a central core completely surrounded with white matter. The fibres in the white matter connect different regions of the spinal cord with each other and further allow impulses to pass from all its levels to the brain-stem and brain and *vice versâ*. One very long tract of white matter carries impulses from the cerebrum to the spinal cord and is probably concerned with skilled movements. The shape of the grey matter on cross section of the cord is characteristic (Fig. 59). On each side will be found a blunt ventral horn containing amongst many others, large nerve cells which are those that give rise to motor nerves; a sharp dorsal horn into which stream afferent fibres; and in some regions of the cord a small lateral horn probably connected with the preganglionic fibres of the autonomic system. The spinal cord, both white and grey matter, is almost divided into two by a deep dorsal cleft or fissure and a shallower and more open ventral fissure. If the spinal cord be dissected out it will be seen that on each side and, at a

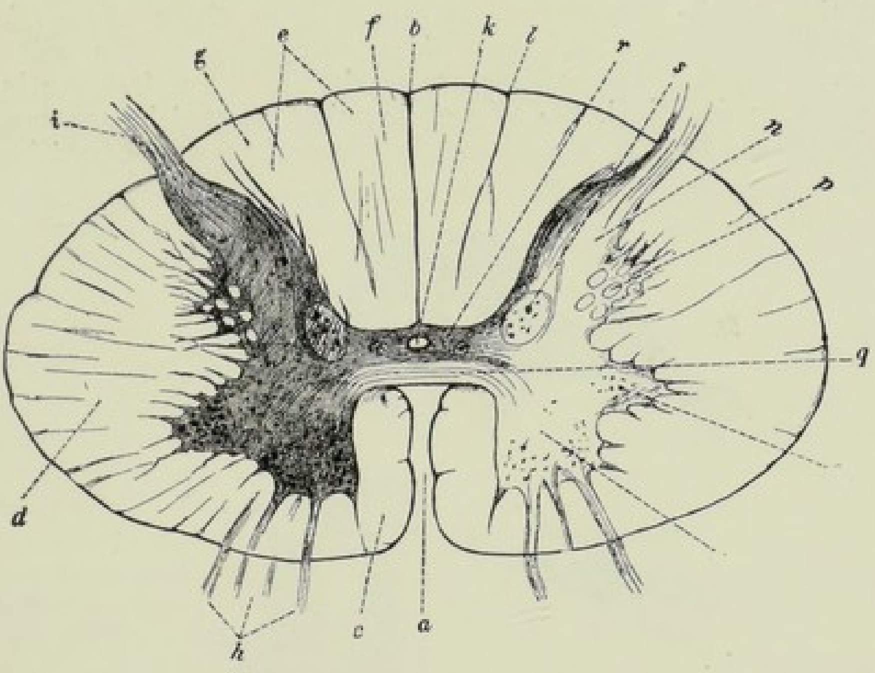

Fig. 59. Transverse section of spinal cord (semi-diagrammatic). *a*, ventral fissure; *b*, dorsal fissure; *c*, *d*, *e*, *g*, white matter; *h*, ventral rootlets; *i*, dorsal root; *m*, ventral horn; *n*, dorsal horn; *o*, lateral horn. (After Erb.)

series of different levels, the peripheral nervous system arises by means of "roots." (Fig. 60). On the dorsal side are the dorsal roots, each with its ganglion attached, in which the nerve cells of the afferent fibres are situated. Each dorsal root is made up of a large number of fibres wholly afferent in character and is connected with the dorsal horns of grey matter and with the dense mass of white fibres on each side of the dorsal fissure. The ventral roots arise, as the name indicates, from the ventral aspect of the cord and are connected with the cells of the ventral horns. In all regions of the cord they contain motor fibres for voluntary muscle but in the thoracic and sacral regions they include preganglionic fibres as well. Each ventral root joins a dorsal root a short distance beyond the ganglion on the latter, and thus a mixed nerve trunk is produced. This condition may be taken therefore as typical of the whole cord—a dorsal series of groups of neurons bringing in afferent impulses and a ventral series allowing an outflow of impulses to voluntary muscle and the organs innervated by the autonomic system.

Afferent impulses reach the spinal cord from receptors in the skin of the trunk, limbs and tail, from the pelvic viscera, to some degree from the abdominal alimentary canal, and from the proprioceptors in the tendons, ligaments, muscles and joints of the trunk, limbs and tail. The motor outflow is concerned with the muscles of the trunk limbs and tail. The thoracic autonomic outflow produces constriction of arteries throughout the body, acceleration of the heart, erection of hairs over the whole skin, dilation of the iris, inhibition of gut movements, &c. The sacral autonomics produce contraction of the colon, rectum, bladder and uterus, and special movements of the genital apparatus in both sexes.

If the spinal cord be cut across in the lower neck region a mammal continues to breathe by its diaphragm and can live many months. In this case the whole of the central nervous system posterior to the cut will be isolated from the higher nerve centres, but it will continue, after a brief period of shock, to act normally. As already pointed out in Chapter III. the function of the central nervous system is to divert afferent impulses along particular paths and lead them eventually to the exit nerves. (Fig. 37.) In this way reflexes are produced. For instance in a dog operated on as described, the afferent impulses, started by movement of a few hairs on the back of the animal, will enter the spinal cord below the

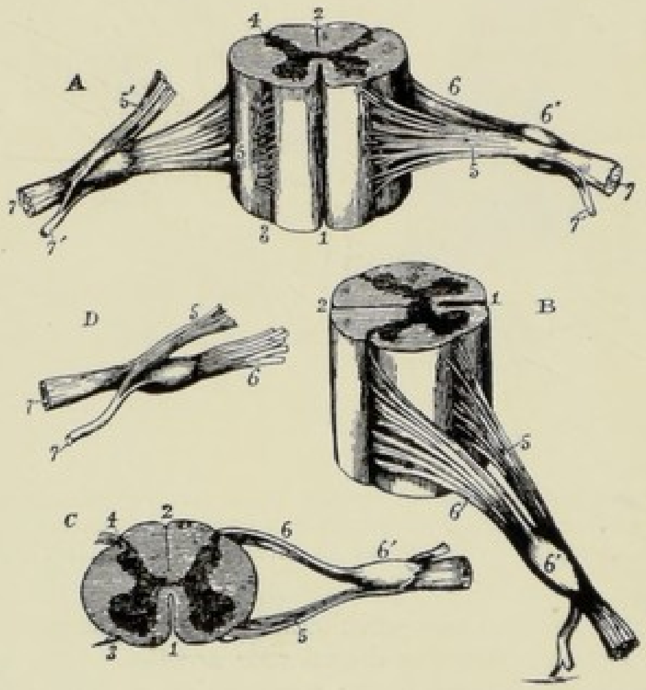

Fig. 60. Different views of a portion of the spinal cord with the roots of nerves.—1, ventral fissure; 2, dorsal fissure; 3, origin of ventral rootlets; 4, tip of dorsal horn with entry of dorsal root; 5, ventral root; 5^1, ventral root divided; 6, dorsal root; 6^1, ganglion on dorsal root; 7 and 7^1, roots combined to form mixed nerve which divides at once into two. (After Allen Thomson.)

cut, will traverse definite channels, and will finally leave by the motor nerves which innervate certain muscles in a rhythmic way and thus produce a movement of the hind limbs which we call scratching. The foot will be applied fairly close to the region tickled though the animal, through the operation, is unconscious of the stimulus and even of its own response. A decapitated frog will scrape off with wonderful accuracy a piece of paper soaked in acid which has been applied to its flank. As another instance may be given the reflexes due to afferent impressions arising from the presence of fæces in the rectum: these enter the spinal cord, are grouped within the grey matter, and finally leave the cord by the nerves, motor and preganglionic, which are concerned with that combined action of muscles, skeletal and smooth we call defæcation. It so happens that in this case the region of the grey matter where the distribution is effected is small and circumscribed and we thus speak of the *centre* for defæcation. A trifling injury to the cord may destroy this centre and rob the animal of its power to defæcate normally. Similarly there are centres for the bladder and for the sexual organs. It must be noted in this connexion that, when muscles are involved in a reflex, it is not enough merely for certain muscles to be activated—others must be stopped or inhibited. Thus in the act of defæcation the sphincter of the anus must relax: when in the act of scratching, the hock is *flexed* it will be found that the muscles which *extend* the hock lose their tautness or "tone" and *vice versâ*. The muscular and visceral reflexes carried out by the spinal cord, as also those of the brain stem, have a distinct purposive character; thus a spot tickled is scratched, fæces and urine are expelled, a limb is withdrawn from a source of injury, &c. In the whole central nervous system, except the fore-brain, we find that the chains of neurons along which the impulses pass are definite and inborn. Certain stimuli or sets of stimuli will provoke certain responses and only these. It will be apparent, from what has been stated above, that a reflex may be lost through injury to receptors, or to afferent fibres, or to the central nervous system, or to exit fibres, or to the receptive substance or active structure of the muscle or gland.

The medulla oblongata is really a continuation of the spinal cord headwards. The typical arrangement of the grey and white matter is however disturbed, the central core of grey matter being broken up by strands of white fibres, whilst special accumulations of nerve cells occur in the midst of the white matter. It is in this region that the great strand of white fibres, on either side, passing from the cerebrum to the spinal cord, crosses from one side to the other and produces what is called the "decussation of the pyramids." It is owing to this decussation that an apoplectic seizure involving, say, the *right* side of the forebrain, conditions a partial paralysis of the *left* side of the body.

In the PONS the distribution of grey and white matter is still further disturbed by the presence of fibres entering and leaving the cerebellum and connecting together the two lateral expansions of this organ. Taking the pons and the medulla together it may be briefly stated that the nerves arising from this region are the 5th cranial or *trigeminal*, the 6th cranial or *abducens*, the 7th cranial or *facial*, the 8th cranial or auditory, containing however fibres from the semi-circular canals as well as fibres from the cochlea, the 9th cranial or *glossopharyngeal*, the 10th cranial or *vagus*, the 11th cranial or *spinal accessory*, and the 12th cranial or *hypoglossal*. The afferent supply of the medulla-pons region is large and embraces the following—from the skin of the forehead and face, the teeth, and the mucous membranes of the mouth, eye and nose—these enter by the 5th; from the organ of hearing and from that great proprioceptive organ, the semi-circular canal system—these enter by the 8th; from the mucous membranes of the pharynx, back of the tongue and the Eustachian tube, and probably from the taste receptors—these enter by the 9th; from the heart and aorta, the trachea, bronchi and lung, and the mucous membranes of the alimentary canal from the œsophagus to the colon—these enter by the 10th; and finally from the muscles innervated by the motor outflow from this region. As the medulla and pons are not isolated from the rest of the C.N.S we accordingly find that the afferents of the spinal cord send up branch fibres that enter here into the grey matter, and similarly afferents entering higher up in the brain-stem make connection with this region by circuitous routes. The motor outflow proceeds to the muscles that move the tongue—by the 12th; all the muscles of the larynx except one—by the 11th; the muscles of the jaws—by the 5th; the muscles of the face—by the 7th; the muscles of the soft palate and the pharynx and one muscle of the larnyx—by the 9th; and the external (posterior) *rectus* muscle of the eyeball—by the 6th. The autonomic outflow is very considerable and includes inhibitory to the heart, secretory to the glands of the stomach, motor to the smooth muscles of the alimentary canal from the œsophagus to the first part of the colon—these pass out by the 10th; secretory to the salivary glands and the glands of the mouth by the 7th and 9th. Perhaps the most remarkable feature of the medulla is the number of centres for various visceral reflexes which it contains—there are, for example, centres for the heart movements, for arterial constriction, for respiration, swallowing, vomiting, and secretion of saliva. The pons contains the centre for closure of the eyelids on irritation of the cornea or strong illumination.

The CEREBELLUM may be regarded as a great expansion of the brain-stem connected with the proprioceptive system. It has a peculiar laminated structure with grey matter external and white matter within. Into it stream branch fibres from the nerves coming from the semi-circular canals and from the afferents of those muscles, tendons and joints that are concerned with body movement and posture. From the cerebellum nerve fibres pass to the brain-stem and particularly to the spinal cord. If the cerebellum be injured, the animal moves in a peculiar reeling or drunken manner or, if the injury be a serious one, may spin round or turn somersaults with considerable violence. The tautness or "tone" of the various muscles of the body not actually in active contraction is partly attributable to cerebellar influence.

The region of the CORPORA QUADRIGEMINA receives scarcely any afferent fibres directly. It has a small motor outflow to the *superior oblique* muscle of the eyeball by the 4th cranial or *trochlear*, and to all the other muscles of the eyeball (except the posterior or external rectus) by the 3rd cranial or *oculo-motor*. The autonomic outflow occurs *viâ* the 3rd nerve and has to do with the ciliary muscle of the eye and the constrictor muscle of the iris. This region contains centres for the adjustment of the pupil to varying strengths of light, for phonation, for quadrupedal progression, and for sneezing.

The region of the THALUMUS is that portion of the brain-stem where branch fibres from all the afferents of true sensation entering the central nervous system meet and then form new relays that spread into the fore-brain. A special protrusion of the thalamic region forms the so-called *optic* nerves (2nd cranial). An upward protrusion forms the pineal gland which is really a degenerated eye; a downward protrusion forms the pituitary gland the use of which is unknown (Fig. 61). The so-called olfactory nerves (1st cranial) are often described as entering the forebrain; they are most likely protrusions from this region. The thalamus contains centres for guiding body movements by vision.

The forebrain, brain proper or CEREBRUM consists of two highly convoluted expansions or hemispheres. As the grey matter is external to the white matter the area of grey matter is increased the greater the intricacy of convolution. The cerebrum has been described as the organ of consciousness and of intelligence. From the physiological standpoint it may be regarded as the organ of memory and of skilled movements. In all the regions of the central nervous system previously described the neuron paths, along which the impulses run, are inborn and are probably not affected in the animal's lifetime. A dog without a forebrain will eat, sleep, bark, growl and bite, but it will never associate its sensations. If fed by a particular man and from a particular vessel it will never link up the sight of the man or the vessel with the act of eating but will struggle violently with its keeper until the food is thrust into its jaws. A human being in a state of complete idiocy is in much the same condition. Into the forebrain there enter relay fibres from all the afferents which give sensations and particularly those of sight, smell, hearing and pain. From the brain there emerge fibres which never pass out of the central nervous system but proceed, firstly, to the grey matter throughout the whole cord which controls muscular movements, and, secondly, but to a much lesser degree, to the various visceral centres. The action of the cerebrum may be

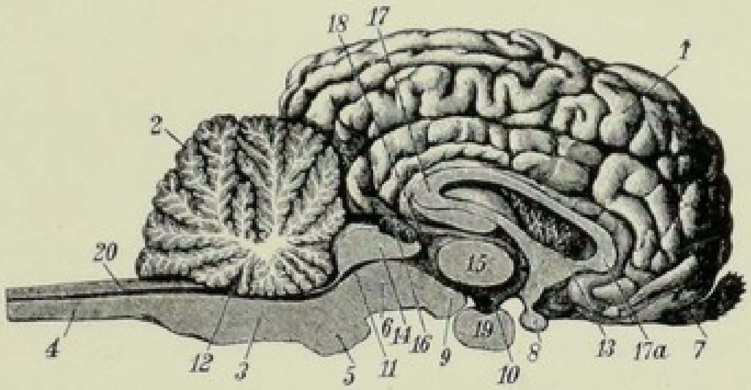

Fig 61. Vertical longitudinal section through brain of horse.—1, left fore-brain or cerebral hemisphere; 2, cerebellum; 3, medulla oblongata; 4, spinal cord; 5, pons; 7, olfactory "nerve"; 8, optic "nerve" cut short; 14, corpora quadrigemina; 15, thalamus; 16, pineal gland; 17, bridge (cut across) connecting the two cerebral hemispheres; 19, pituitary body. (After Hagemann.)

looked on largely as an interference with the reflex mechanisms of the rest of the C.N.S.; some of the fibres start or augment, a great many can check reflexes; other fibres can set muscles acting in a particular combination and sequence that would never occur in any reflex at all. These last mentioned, which have to do with skilled movements, show increasing development the higher the animal is in the evolutionary scale. When the heart's action is increased by fear, when the saliva and gastric juice are secreted on merely seeing preparations being made for a meal, we have two of the many instances of the action of the forebrain on visceral reflexes.

We may regard the nerve paths (or the synapses—see Chapter III.) in the forebrain as being sensitised so that the passage of a particular group of impulses produces an actual physical change and allows subsequent impulses to pass more readily along these paths. This is the physical basis of memory whereby past experiences are registered and to it we may ascribe also the fact that "an act repeated becomes a habit" &c. An animal possessing a cerebrum can guide its conduct by its own previous errors and successes, whilst human actions can be regulated not only by these but also by the experiences of others properly communicated, by true reasoning, and by ideals. But bereft of its forebrain an animal is a pure automaton whose responses to stimuli are predestined and predictable.

CHAPTER XVII.

Reproduction.

In all vertebrates, except the degenerate sea-squirts, reproduction takes place sexually, that is to say each individual arises by the union of a cell called a sperm cell or SPERMATOZOON derived from the male, with a cell called an OVUM derived from the female. In Chapter II. it was shown that every higher animal and plant is built up of cells each of which contains a nucleus. Now in every nucleus there are present a number of structures like short pieces of microscopic twine called chromosomes (see Fig. 9). The number of chromosomes in each body cell is constant for the members of a particular species. Thus in some snails there are 32; in the mouse, trout, and lily there are 24; in the ox, guinea-pig, man, and the onion there are 16. Now it is found that in the spermatozoon and also in the ovum the number of chromosomes is exactly one half that in each of the body cells; when therefore these two cells fuse together in what is called the fertilization of the ovum the correct number of chromosomes—and therefore an efficient cell—is produced. There is some reason to believe that the chromosomes are those structures which are responsible for the transmission of ancestral characters to the offspring.

The spermatozoa arise in two testes or testicles. Each spermatozoon is composed of a head, a neck and a tail, the last mentioned part keeping up a constant side to side or wriggling movement, so that the spermatozoon can move spontaneously and is thus able to travel several inches or even a few feet on a moist surface before exhaustion sets in. The spermatozoa are microscopic in size, being about $\frac{1}{500}$ inch long for most of the larger mammals. The spermatozoa floating in an albuminous fluid pass from each testicle through a highly convoluted tube and then through a straight tube close to the neck of the bladder where in most mammals a SEMINAL VESICLE or reservoir is found. In the sexual act the secretion of the testicle is mixed with the secretion of other glands such as the prostaté, and the mixed fluid or SEMEN is ejaculated through the urethra to the end of the penis and thence into the vagina or uterus of the female. The number of spermatozoa injected in a single insemination is very large being expressed as hundreds of millions for most mammals. When the semen arrives in the vagina or uterus the powerful tail movement of each spermatozoon urges it forward, the direction being always the same and probably determined by a chemical substance which is present in the moisture of the genital passages of the female and which increases in strength from without inwards. What may now be described as a race takes place. The spermatozoa travel through the uterus and up the Fallopian tubes attached to the uterus. Should an ovum be present in the upper part of a Fallopian tube, or even at the beginning of this tube in the abdominal cavity, the first spermatozoon to arrive enters it and fertilizes it and immediately the ovum alters its outer layer or tunic so that no more spermatozoa can enter. (Fig. 62.) There is probably here a provision of nature for selecting the most vigorous spermatozoon in somewhat the same way that the queen bee selects the most vigorous drone during her nuptial flight.

The cells that give rise to spermatozoa in the testes are laid aside for this purpose at a very early stage of development—long before birth—but they do not become active until puberty which takes place at an age varying with each species. The production of spermatozoa is not the only function that the testes carry out; these two glands are undoubtedly the seat of formation of chemical messengers or hormones which pass into the blood stream and influence most regions of the body. At puberty, beside sexual power and desire, a number of secondary characters occur in the male such as changes in the vocal chords and larynx giving the broken voice, increased growth of hair, increased muscular, mental and emotional activity, &c., which are referable to hormones derived from the testes. If an animal be castrated before puberty these secondary sexual characters do not appear; in such an animal however development of these missing characters can be stimulated by grafting a testis from a male of the same species somewhere in the body.

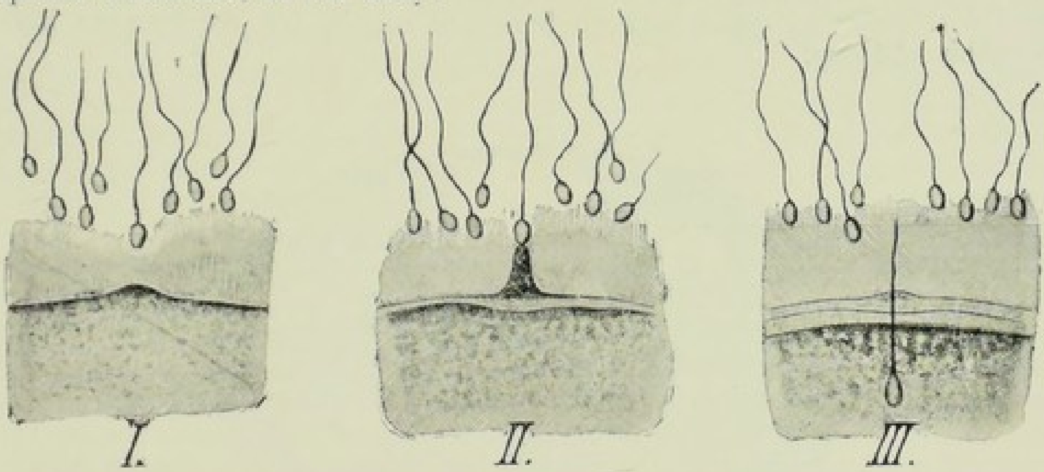

Fig. 62 Fertilization of an Ovum, Highly Magnified.—I. A number of spermatozoa have reached the border of the ovum. An alteration in the tunic of the ovum takes place opposite the foremost spermatozoon. II. and III. Stages in the entry of the foremost spermatozoon; the others are refused admittance. (After Hagemann.)

The ova are formed in the two glands of the female called ovaries. The cells from which the ova arise are already laid aside in the mammal long before birth, but do not become active until puberty is reached. After this age until sexual activity ceases, a process of ripening of the ova can be observed in each ovary. (Fig. 63.) From time to time an ovum sinks in the ovarian tissue and gets enclosed in a hollow sphere of cells or FOLLICLE containing a fluid; this sphere gradually works to the edge of the ovary and then bursts, liberating the ovum into the abdominal cavity. This process, ovulation as it is called, will occur if access is denied to the male but though not entirely dependent upon the sexual cycle it is hastened both by the state of the genitalia in the period of œstrus or sexual desire and by copulation with the male. The ovum in the abdominal cavity in some manner not thoroughly understood is carried (possibly in a purely passive way by the writhing of the pelvic gut) to the mouth of one of the two Fallopian tubes. It is then apparently seized by the tentacular mouth of the tube and driven slowly towards the uterus by peristalsis. Should no spermatozoon be present the ovum passes through the uterus and thence into the vagina and so is discarded. But should a spermatozoon enter into the ovum fertilization will occur. When the spermatozoon bores into the ovum its tail drops off but the head and neck parts enter and blend with the nucleus of the ovum. When fertilization occurs the ovum at once begins to change. It divides into two, then into four, and so on, each daughter cell growing at the expense of nutriment derived from the mucous membrane of the tube. In this process of division it is interesting to note that each daughter cell has the same number of chromosomes as the original fertilized cell; for by a process of division, like the splitting of a cane longitudinally, each of the chromosomes of the mother cell divides into two, making a complete set for each cell, and each of the daughter chromosomes can divide longitudinally and so on. Thus it is that in every cell of the adult body the chromosomes are derived half from the mother and half from the father. The mass of cells to which the ovum has given rise passes down the Fallopian tube into the uterus and there lodges becoming firmly adherent to the uterine wall. Its further development will be considered later. In the mammal an ovum is utterly incapable of developing unless fertilized by a spermatozoon, and the spermatozoon must emanate from a male of its own species or at least of species very closely akin. Thus successful pairing can occur between hare and rabbit, but not between hare or rabbit and dog.

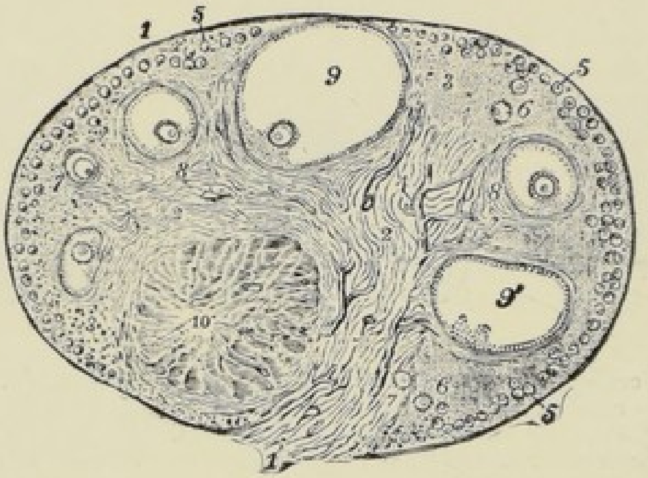

Fig. 63. Section of the Ovary of a Cat.—1, outer capsule; 5, cells from which ova arise; 6, similar cells enlarging and sinking deeper, and ultimately forming follicles; 7 and 8, unripe follicles; 9, ripe follicle, about to burst and shed ovum; 10, corpus uteum. (After Schrön.)

In the female, as in the male, secondary sexual characters are dependent on hormones emanating from the active ovaries. If the ovaries are removed before puberty these secondary sexual characters will not appear but they can be induced by grafting into some organ of the body (say the kidney) the ovary of a female of the same species. The ovary can also through its hormones produce a number of significant changes in the body. Thus the sexual cycle in the female, the growth of the mammary gland, the regulation of the amount of fat in the body, the changes in the uterus during pregnancy, and even the continued existence of the uterus itself are due to chemical messengers arising from this important organ.

The ova in a mammal are microscopic in size, being about $\frac{1}{150}$ inch in man, whereas in the bird the ovum is enormously swollen by a supply of food for the embryo called the yolk.

The Sexual Cycle in the Female.

In all female mammals after puberty a definite cycle of changes is observed in the genital organs when pregnancy has not occurred. These changes have been named as follows—PROŒSTRUM or period of preparation, ŒSTRUS or period of sexual desire, METŒSTRUM which occurs if fertilization is absent and is a period of subsidence of genital excitement, and the ANŒSTRUM or period of rest in which the sexual organs lie fallow. At the end of the anœstrum a new sexual season occurs and the cycle begins again with the proœstrum. Animals that conform to this type are termed MONŒSTROUS. Examples of monœstrous animals are many wild sheep in which the sexual season occurs once a year and the anœstrum or fallow period extends over several months. Another monœstrus animal is the domestic bitch in which however the anœstrum last only a few months and so three or even four cycles can take place in a year. The other type has been termed POLYŒSTROUS; in this case, in the absence of fertilization, there takes place after the metœstrum instead of a long anœstrum, a very short fallow period of a few days called the DIŒSTRUM, then a new cycle beginning with proœstrum starts again. After a few of these cycles a true anœstrum appears and lasts until a new sexual season occurs. As an example of a polyœstrous animal the mare may be taken. During a certain portion of the year she passes, when not pregnant, through a series of cycles separated each from the other by a short diœstrum, then a true anœstrum occurs and ends with the advent of a new sexual season. The polyœstrous condition is shown by domesticated cattle, sheep, and pigs. An extreme form of polyœstrous rhythm is displayed by man, certain monkeys, and some domesticated sheep. Here the anœstrum is absent and the cycles are separated only by short diœstral periods and the female is therefore capable of being impregnated throughout the year. But in most polyœstral animals the diœstrous cycles are only two or three in number. Domestication and change of climate and food have a marked effect on these cycles. Generally stated domestication tends to shorten or even obliterate the anœstrum and thus make the periods of œstrous or desire more frequent though possibly less intense.

The period of proœstrum has been termed the period of preparation, *i.e.*, preparation for a fertilized ovum. The external genitals become swollen and a discharge takes place from the vagina which may be bloody; there is also some general excitement and in some animals special indications, such as drooping ear in the sow, and blood-shot eye in the rabbit. But it is in the uterus that the most significant changes happen. The lining membrane thickens and its blood vessels become enormously dilated; some extravasation of blood beneath the surface generally occurs and may, in some animals, be so pronounced as to cause true bleeding into the uterine cavity. The innermost layer of the uterus breaks down in part and passes out as a mucous discharge, in some animals mixed with blood. These uterine changes may be regarded as all preparatory for the reception of a fertilized ovum. Immediately following the proœstrum is the œstrus or period of desire in which the male is sought. Its duration is short and rarely exceeds twenty-four hours. In many animals the female in œstrus possesses an odour which informs the male of her condition and excites him sexually. The œstrus in some animals, *e.g.*, sheep, may overlap the proœstrum to some extent. If the sexual act takes place, and should a fertilized ovum arrive in the uterus from either Fallopian tube, the uterine wall is now in a fit condition for the attachment and nourishment of the ovum. Pregnancy begins and the sexual cycles are intermitted. But should no such ovum arrive the uterus returns to its normal state in a period of metœstrum. Then follows a resting stage of anœstrum or diœstrum and then the cycle begins afresh. Not only pregnancy but lactation (nursing) may check the occurrence of these cycles. This rule, however, is not without exceptions for many rodents may suckle a litter of young while pregnant with another litter, and the mare generally experiences œstrus nine days after giving birth to a foal.

Pregnancy.

The number of fertilized ova that reaches the prepared uterus at one time varies with the species of animal. In the larger mammals one only is the rule. In the cat three to six, in the dog four to ten, and in the pig six to twelve ova are fertilized at the same time. In the bird and lower animals the fertilized ova leave the body with a supply of nourishment and continue their development outside the mother. In mammals however the ova depend from the first for nourishment on the maternal uterus. When the small mass of cells formed from a fertilized mammalian ovum reaches the uterus at the proper stage in the sexual cycle it remains adherent to the uterine wall. Subdivision and growth of the cells occur rapidly. After a short time a grouping of cells is evident, and the beginnings of skin, gut, and central nervous system become apparent. So far the nourishment required has been derived by simple absorption from the secretion of the uterine lining membrane, but when the embryo develops a system of blood vessels and a heart a more efficient method of obtaining nourishment is required. The embryo encloses itself in a bag containing a watery fluid and composed of a fairly tough membrane. The wall of the bag fits itself to the wall of the uterine cavity. The chief use for this is to shield the delicate embryo from injury and also to bear the brunt of the work of dilating the neck of the uterus and the vagina when the young is born. From a point in the embryo, which is afterwards recognised as the navel, a curious outgrowth arises called the ALLANTOIS, which eventually blends with a portion of the wall of the membranous bag to form the PLACENTA. The placenta sends long finger-shaped processes into similarly shaped depressions in the uterus which are lined by walls richly supplied with blood vessels. Two arteries from the embryo pass along the stalk of the allantois and break up into a dense meshwork of capillaries in the placenta ; then the blood is collected into venules and finally into one large vein which runs parallel with, and close beside, the two arteries mentioned and brings back purified and enriched blood to the embryo. It must be remembered that there is no direct connexion between the blood of the fœtus and that of the mother. The embryonic heart pumps blood through its own body and through the placenta. In the finger-shaped processes or *villi* of the placenta the separation from the maternal blood is effected by a very thin membrane through which the exchange takes place. The blood of the fœtus takes up oxygen from, and gives off carbon dioxide to, the maternal blood. It was formerly thought that the nutriment required by the embryo simply filtered through from the uterine blood vessels into the capillaries of the placental villi, but there is reason to believe that the placenta is a digestive organ breaking down the necessary constituents of the maternal blood and passing them into the blood of the fœtus. The stalk of the allantois with its vein and two arteries is known in the later stages of embryonic development as the UMBILICAL CORD. The shape and attachment of the placenta varies in different species of mammals ; in some the finger-shaped processes or villi are simple and when the young is born are detached from the uterine wall without producing any tearing. In such cases the placenta comes away without any portion of the uterus being attached to it—such placentas are termed *indeciduate*. In others the villi are so locked in the uterine tissue that when the young is born the villi drag with them pieces of the inner wall of the uterus and leave what may be termed an open sore at the site of the placental attachment. Such cases are called *deciduate*. We may classify placentation roughly as follows:—

Deciduate	Meta-discoidal—the villi are at first scattered, but are collected into a disc—man and monkey.
	Discoidal—the villi are restricted to a cake-like disc—rodents.
	Zonary—the villi are restricted to a belt-like band—carnivores, elephant.
Indeciduate	Cotyledonary—villi in patches—ruminants.
	Diffuse—villi scattered—pig, horse.

As development proceeds the cells of the embryo increase continually by subdivision and the organs approach nearer and nearer to the condition that they present at birth. One extraordinary fact about embryonic development is that a number of stages are traversed which are singularly reminiscent of stages in the evolutionary ascent of the race. Thus all mammalian and bird embryos at one period of growth show clefts in the throat like the gills of a fish, and the human embryo at one time possesses a tail.

From the moment of entry of the fertilized ovum the uterus begins to change. Instead of the metœstrum a long series of important alterations takes place too complex for full description here. The uterus grows parallel with the growth of the embryo and the membranous bag of the latter, its muscular walls increase enormously in thickness and in the size and power of the constituent muscular cells, and, where the placenta is to be formed, an alteration in the inner wall is effected. These important changes in the uterus are the outcome of hormone stimulation. The developing ovum unquestionably furnishes one set of hormones, but these would apparently be useless unless backed up by hormones arising from the ovary and probably from one particular part of the ovary called the corpus luteum (Fig. 63). The corpus luteum is produced from a burst follicle and was originally thought to be only a lump of scar tissue but its secretory importance has been proved beyond doubt for if it be destroyed, or if it fail to develop, pregnancy comes to a premature end. What exactly determines the onset of parturition or labour has not been discovered. The muscular walls of the uterus contract powerfully in a series of "pains." Thanks to the membranes containing the watery fluid, the narrow neck of the uterus can be dilated without injury being done to the head or fore limbs of the fœtus. The pains continue until the membranes burst and the young, after undergoing a characteristic rotation, is driven through the vagina; after a variable interval the membranes and placenta are ejected by further uterine contraction. Once the placenta has been detached from the uterine wall the young animal can no longer get its oxygen from the maternal blood; slight asphyxia therefore ensues and through the stimulation of the respiratory centres by the asphyxial blood the first breath is taken. Coincidentally with this a change takes place in the heart so that the right ventricle which in the fœtus sent its blood into the aorta now drives blood into the lungs through the pulmonary artery and the condition of the circulation present in the adult is established. After the expulsion of the placenta and membranes the uterus rapidly contracts upon itself and undergoes a sort of degeneration, becoming smaller and less muscular, and finally approaches the state characteristic of the non-pregnant female. Its contraction is greatly aided by a nervous reflex started by the young sucking at the teat.

Time Interval between Œstrus and Œstrus in Non-pregnant State.		Time Interval Between Parturition and Return of Œstrus.
Mare	3—4 weeks	5—9 days.
Cow	3—4 weeks	21—28 days.
Sheep	17—28 days	7 months.
Sow	9—12 days	4—5 weeks, usually 8—9 weeks, maximum.
Bitch	12—14 weeks (anœstrum	2 months.

Average Duration of Gestation.

Ass	365 days.
Horse	340 ,,
Horse (better breeds)	350 ,,
Cow	283 ,,
Man	280 ,,
Goat	154 ,,
Sheep	152 ,,
,, (merino)	150 ,,
,, (southdown)	144 ,,
Pig	120 ,,
Dog	63 ,,
Cat	56 ,,

Age of Puberty.

Rabbit, rat, in 1st year.
Cat, dog, sheep, pig, in 2nd year.
Horse, cattle, in 3rd year.
Man, in 14th year.
Elephant, between 20th and 30th year.

Period of Suckling.

Foal	12—20 weeks.
Lamb	8—16 ,,
Calf	6—12 ,,
Pig	4—8 ,,

Incubation Period of Eggs.

Goose	28—33 days.
Duck	28—32 ,,
Turkey	26—29 ,,
Hen	21 ,,
Pigeon	17—19 ,,

CHAPTER XVIII.

Lactation.

The mammary glands vary in number in different animals. In the cow there are really two, for the udder, though apparently single, is divided completely by a fore and aft partition of strong connective tissue which completely separates the two glands. Each gland has one or more main ducts and teats. The mammary glands increase in size at puberty but such increase is largely due to connective tissue and fat. When, however, the animal becomes pregnant the true glandular matter undergoes great increase. This response of the mammary gland to pregnancy has been proved to be due to hormone stimulation, but a doubt has arisen as to the origin of the hormones. Probably such origin is twofold—from the ovary and from the fœtus. In an animal in the wild state no secretion of milk takes place, except when suckling, but, in domesticated animals, milk secretion may occur throughout pregnancy and even in the virgin state. Certain evidence points to the fact that from the fœtus or its placenta a hormone enters the blood stream which, reaching the gland, holds secretion in check. The moment the placenta is detached this restraining agent is removed and the gland begins to secrete actively. In the highly selected and domesticated milch cow pregnancy does not stop the formation of milk though it certainly lessens the amount secreted in the later months.

The mammary gland is a true gland and its product a true secretion. The chief ingredients of milk do not appear preformed in the blood but are manufactured by the gland cells out of the nutriment supplied by the blood. In one respect the secretory epithelium of the mammary gland is unique. The lining cells, when active, not only produce a secretion but apparently break up, in whole or part, and pass into the secreted fluid. Milk is to a certain extent a cell pulp as well as a fluid secretion. The cells that are thus mutilated or lost are speedily repaired or replaced by cell growth and subdivision. The mammary gland has a fine substructure of connective tissue, embedded in the meshes of which lie the true gland cells. It is plentifully supplied with blood vessels, lymphatics, and nerves. The ducts leading from the small gland follicles or *acini* join together to form larger ducts, and so on until one or two large ducts are formed which pass each through a teat. One peculiarity of this duct system is the presence of reservoirs, the largest being just at the root of the teat. Another curious and important fact is, that in the branching part of the duct system, sphincter muscles occur over which the animal has some control. The teat is also well supplied with sphincter muscles. Closure of the ducts can occur reflexly through fright, unfamiliar surroundings, or œstrus, but it is certain that cows can acquire a pernicious habit of voluntarily holding their milk on the slightest provocation. In some cows the sphincter of the teat is so toneless that the mere pressure of the milk in the udder is sufficient to force it open. If milk is allowed to stagnate in the ducts and their reservoirs there is a partial back absorption of some of the ingredients; such milk tends to check further secretion and may induce inflammatory trouble through irritation. The secretion of milk is not under the control of the will but can be affected by the physical and mental state of the animal. Thus the quantity will diminish through sexual excitement, fatigue, insufficient food or water, &c. The secretion of milk becomes very active when the calf is sucking, and even during the act of milking. In consequence the milk gained by the calf or milker may be more than that simply stored in the ducts and reservoirs.

Physical Characters of Cow's Milk

The average specific gravity of cow's milk at 60 deg. F. is about 1,032, that is to say, 1,000 volumes of milk would weigh as much as 1,032 volumes of water at the temperature specified. As the fat in milk has a specific gravity lower even than water it follows that the specific gravity of separated milk is higher than that of whole milk. The white colour of milk is due partly to the fat being in a state of emulsion and partly to the caseinogen of the milk being to a slight degree also in a state of suspension. The yellowish tinge is due to a pigment associated with the fat. The sediment present in uncontaminated cow's milk is very slight in amount and is composed of fibrin threads which have formed in the milk itself and epithelial cells shed by the lining membrane of the ducts in the udder and teat. During the colostral period (lasting a few days after parturition) milk contains cellular elements—colostral corpuscles—which represent the débris of incompletely broken-down gland cells. Fresh milk is slightly acid to some indicators owing to the presence of phosphates and caseinogen.

Constituents of Milk

1. Caseinogen. This is a complex protein containing phosphorus. It is an acid and is insoluble in water. In milk, however, it occurs as a salt of lime which is soluble. When acid is added to milk, or if the milk develops lactic acid on standing, a clot is formed which is due to the added acid seizing upon the lime and turning the insoluble caseinogen out of combination. When milk is subjected to the action of a protein-splitting ferment such as rennin, trypsin, &c., a totally different form of clotting occurs. The caseinogen is altered chemically being transformed into casein and cannot be restored to its original state. Caseinogen in solution as salt is not precipitated by boiling but it forms a tough skin on the surface. The whole of the caseinogen in milk is not in solution; part is in suspension unattached to lime and thus the white colour of separated milk is produced. Caseinogen is soluble in alkalies and in strong excess of acids, but it is insoluble in weak acids.

2. Lactalbumen. This is a true albumen being coagulated by heat. It differs only slightly from the albumen in blood. In colostral milk the content of lactalbumen is very high and the milk will, if heated, form a firm clot.

3. Fibrinogen. A very small amount of fibrinogen is present which undergoes spontaneous transformation into fine gelatinous threads of fibrin.

4. Fat. Milk contains a mixture of fats, each being composed of a fatty acid and glycerine. The preponderating fatty acids are oleic, palmitic, myristic, and butyric. The fat is held in suspension in the form of microscopic globules each surrounded by a jacket of precipitated caseinogen. When milk stands the globules rise to the surface as cream. This action, as is well known, can be accelerated by centrifuging.

5. Lactose. This is a disaccharide sugar, as already explained in a previous chapter. Lactose does not readily undergo alcholic fermentation but is very readily attacked by various bacilli, becoming transformed into lactic acid—hence the spontaneous souring of milk.

6. Salts. Chlorides and phosphates of soda, lime, potash, and magnesia are present, but the preponderating salt is phosphate of lime as this is needed for the rapid bone growth of the young animal.

7. Lipoid. Lecithin and cholesterin are present in varying amounts in the milk of different species.

8. Organic acids. These reckoned as citric acid are present in cow's milk to the extent of about 0.25 per cent.

9. Other substances. Without doubt there are many substances present in small quantities which further research will discover and estimate. There is evidence that milk contains antitoxins which are absorbed best in the colostral period; also enzymes, the use of which is unknown; the precursors of hormones, &c. The pigment has already been mentioned.

We may regard milk as a perfect food for the young of the same species as the milk-secreting animal. It is impossible to alter the milk of any animal to make it suit the requirements of the young of another species.

AVERAGE PERCENTAGE COMPOSITION OF THE MILK OF VARIOUS ANIMALS.

—	Cow.	Goat.	Sheep.	Mare.	Ass.	Sow.	Human.
Water	87·4	87·3	84	90	92·5	82·4	90
Caseinogen	2·9	3	4·3	1·25	1·06	6·1	1·2
Lactalbumen	0·5	0·5	1·3	0·75	0·79		0·5
Fat	3·7	3·9	5·4	1·1	0·4	6·4	3·1
Lactose	4·8	4·4	4·1	6.7	5	4	5
Salts	0·7	0·8	0.7	0·3	0·4	1·1	0·2

Variation in Milk.

The milk of all mammals varies somewhat with the period of lactation to suit the needs of the young. Variations in food supply affect chiefly the quantity but not the relative proportions of the ingredients. The milk fat can alter slightly in character when certain oily foods are administered. Thus linseed meal gives a butter with a low melting point and bran one with a high melting point. Stagnation of milk in the udder causes a fall in the fat content. The breed of the cow is a most important consideration, witness the high fat content of milk from Jersey cows and the much lower fat content of milk from Ayrshires. In milking the last drawn milk is much richer in fat than the first drawn. This is probably due to a number of factors, one of them being that the larger fat globules meet with more resistance in passing through the small ducts and so come out only towards the end of milking. When the food of a lactating mammal contains highly diffusible and strongly flavoured substances these are apt to appear in the milk after a short interval of time. If the food in question be not repeated the highly flavoured substances will be reabsorbed into the blood and removed from the system by the kidneys. Thus if a cow has a feed of cabbage or garlic and is milked a few hours afterwards the milk is strongly tainted with undesirable flavouring matter; but if the milking be carried out immediately after, or twelve hours after the feed, the milk may be free from the objectionable flavour.

Heredity.

It has been shown that in the fertilised ovum and therefore in every cell in the adult body the chromosomes are derived half from the mother and half from the father. If we regard the chromosomes as conveying the special characters of each parent we might expect to find that the offspring is a blend of its parents and ancestors. In fact Galton has framed a noted law of ancestral inheritance which states that the two parents contribute between them on the average one half of the total heritage of the offspring; the four grandparents one quarter; the eight great grandparents one eighth, and so on. It should be noted, however, that this law would only hold true if a large number of cases were taken and the average computed. Elaborate statistical investigation has shown that such qualities as size, duration of life, and fertility, follow Galton's law. But it must be admitted that certain qualities do not, and here we enter on controversial matter. In 1865 Gregor Johann Mendel read a paper on the results he had obtained with crossing peas. His work excited no interest until 1900, when the experiments were repeated and confirmed and *Mendel's law*, as it is called, gaining a footing in biological circles. In Mendel's law there are two distinguishing features. One is that certain characters may be *dominant* and others *recessive*. Thus a grey mouse mated with a white mouse will have grey offspring. Greyness here is dominant and whiteness recessive; but the offspring are true hybrids for they will have some white among *their* offspring. The second feature in Mendel's law is that it allows us to calculate the distribution of certain characters amongst the offspring. An example or two will make this point clear. A black fowl of a certain type mated with a splashed white of a certain type will give a hybrid which the fancier in his ignorance has termed pure-bred Andalusian. If we mate Andalusian with Andalusian the result is that the offspring arise in the following ratios—one black, two Andalusians, one splashed white. If the parental characters are represented by D (dominant) and R (recessive) then if D is mated with R the offspring will all be DR. If DR be mated with DR then the offspring will be DD, DR, RD, RR, which may be written DD, 2DR, RR; if the dominance be very marked the proportion will appear as three dominants to one recessive. Take as another example the susceptibility of wheat to "rust." The quality of immunity is recessive, that of predisposition is dominant. When an immune strain and a predisposed strain are crossed the resulting hybrids are all susceptible. But if these hybrids are allowed to self-fertilize then dominant susceptibles and recessive immune plants are produced in the calculated ratio of three to one. A more complex example is that in which a pea plant yielding green and round peas is crossed with one yielding yellow and wrinkled peas. Now round and yellow are both dominant, whilst wrinkled and green are both recessive. The hybrid therefore will be yellow and round. If such a hybrid pea plant be self-fertilized the progeny will be found to follow the proportions which can be calculated, namely 9 yielding yellow and round peas, 3 yielding yellow and wrinkled, 3 yielding green and round, and one yielding green and wrinkled.

It is a matter of the greatest importance that future research in this field should give such results that the breeder will know what characters follow Mendel's law and what do not. As an example of an exception may be mentioned the crossing of Border Leicester rams and Cheviot ewes giving a hybrid which breeds true to its type. Also the various characters may, in the future, be classified according to their degree of dominance or recessiveness. Thus, in the case of poultry, rose comb, white plumage, feathered shanks, and brown eggs are supposed to be dominant as against the recessive leaf comb, black plumage, bare shanks, and white eggs.

Some Debatable Points in Heredity.

Maternal Impressions.—That the offspring whilst still in the uterus can be influenced by faulty nutrition or disease of the mother is admitted by all; that it can be influenced by things witnessed or cogitated by the mother is an idea as old as Holy Writ. While firmly believed in by the majority of breeders it is regarded as due to unscientific observation by most if not all expert biologists.

Telegony.—This word is used for "the supposed influence of a previous sire on offspring subsequently borne by the same female to a different sire." This also is believed in by most breeders, but all experiments at biological laboratories and farms have failed to give a single instance of it.

Inheritance of Acquired Characters.—Acquired characters are those which result from the action of external agencies upon the organism in contrast to those that arise or reside in the sexual cells. Thus, in man, change of residence to a hotter climate will darken the skin; certain trades will give distinguishing characters of hand, skin, limb, and muscle; a skilful movement repeated many times will give facility in performing the movement through changes in the nervous system and the limbs. The question arises—can these be transmitted to the offspring? Some of the earlier upholders of the evolutionary theory believed strongly that such was the case. A giraffe, for instance, was supposed to have acquired a long neck through the perpetual stretching of it for many generations in order to reach the leaves of trees. Though the subject is still *sub judice* it may be stated that by far the majority of biologists declare that such transmission does not exist. There is not only evidence against this view such as the non-transmissibility of mutilations, but further it may be definitely stated that there is no instance so far of supposed transmission of acquired characters which cannot adequately be explained by assuming that variations took place in the reproductive cells and that natural selection was able to insure permanence to those animals that possessed an advantageous variation, and was able to weed out those that did not possess it. The reproductive cells, both of ovary and testis, are set apart in a very early stage of embryonic life and it is difficult to see how they could be affected by alterations in an animal's structure due to the animal's own activity or to the action of an altered environment. Of course malnutrition or disease may influence the sexual cells like any other cells of the body but this does not affect the argument.

Variation.—The Darwinian doctrine of evolution assumed that variations of almost imperceptible character were constantly occurring. If a variation were of any advantage it persisted through natural selection and so in course of time the variation became cumulative. There is however some evidence for the view that, at any rate in plants, variations may arise of unexpected magnitude and further that such variations do not arise at all times in the history of a species or race but are limited to restricted epochs. Thus all the specimens throughout the world of *chelidonium laciniatum*, a celandine, are descended from an ancestor that appeared in 1590 in the garden of an apothecary in Heidelberg. In 1887 Professor De Vries found two new specimens of evening primrose in a deserted potato field near Amsterdam. These bred on the whole true to type, but showed unmistakable evidence of a power to alter by leaps and bounds and not by the slow changes which Darwin considered the rule. To this form of variation Professor De Vries gave the name *mutation*. So far instances of mutation have not been clearly demonstrated in animals.

CHAPTER XIX.

The Ductless Glands

So far as our present knowledge is concerned the most unsatisfactory chapter in physiology is that dealing with those organs which have been termed the ductless glands. As the name implies these structures are devoid of any visible efferent channel carrying a secretion. In the case of some of them it is indeed doubtful if any secretion is formed at all, in which case the term "gland" is wrongly used. As regards the functions of the ductless glands we know next to nothing. That they play a most important part in the economy of the body has been proved beyond doubt by pathological evidence and in the case of some of them by the disastrous results that follow their removal.

LYMPHATIC GLANDS.—In the chapter on the circulation it was shown that the living cells of the body are bathed in lymph, which fluid can be regarded as a filtrate that has oozed through the thin walls of the blood capillaries. The spaces between the body cells are filled with lymph and these spaces open into minute vessels, the lymphatic capillaries, which convey the lymph into larger lymphatic vessels and so on until the whole lymph stream is discharged back again into the blood. The flow of lymph is very sluggish and, in the case of the limbs, is practically absent unless the limb be moved or massaged, in which case the lymph is worked along the vessels owing to the rich supply of valves with which these are supplied. But before the lymph is allowed to re-enter the blood it is obliged to pass through at least one lymphatic gland. The lymphatic glands are masses of lymphoid or adenoid tissue, a structure composed of a very open frame-work loaded with round white cells which are remarkably like some of the white cells of the blood. The lymphatic vessel as it enters the gland breaks up into a number of finer vessels and the lymph thereby is brought into intimate contact with the cells of the gland. It is highly probable that here we have a protective mechanism by which toxins, or the bacteria themselves, are destroyed. If, for instance, inflammation occurs in a limb the lymphatic glands (such as those in the human groin), through which the lymph draining the infected area passes, swell up and become painful. If the toxins be in excessive amount they may be able to run the gauntlet of the glands successfully and so enter the circulation producing profound constitutional disturbances. Malignant tumours are very liable to spread along the lymphatic vessels and infect the glands often fairly remote from the original seat of mischief.

In the alimentary canal we find masses of lymphoid tissue placed superficially in the mucous membrane. These belong to a slightly different category from the lymphatic glands proper because they are not situated in the course of a lymph stream; but the tissue of which they are composed is practically identical with that in the lymphatic glands. At the back of the mouth on each side and guarding the entrance to the pharynx we have the tonsils and in the upper part of the pharynx itself a ring of lymphoid tissue is found which, when swollen, constitutes the well known *adenoids*. In the small intestine the lymphoid masses are known as Peyer's patches. Then in connexion with the cœcum there is a definite mass of this tissue which in some animals (as in man) is so pronounced as to constitute a distinct organ, the vermiform appendix. Of the functions performed by these lymphoid organs we know nothing. The only surmise possible is that they act antagonistically to invading disease germs, but it must be admitted that they are themselves singularly liable to bacterial aggression; thus, as in the human being, the tonsil is attacked by scarlatina and quinsy, Peyer's patches by typhoid, and the appendix by various inflammatory processes.

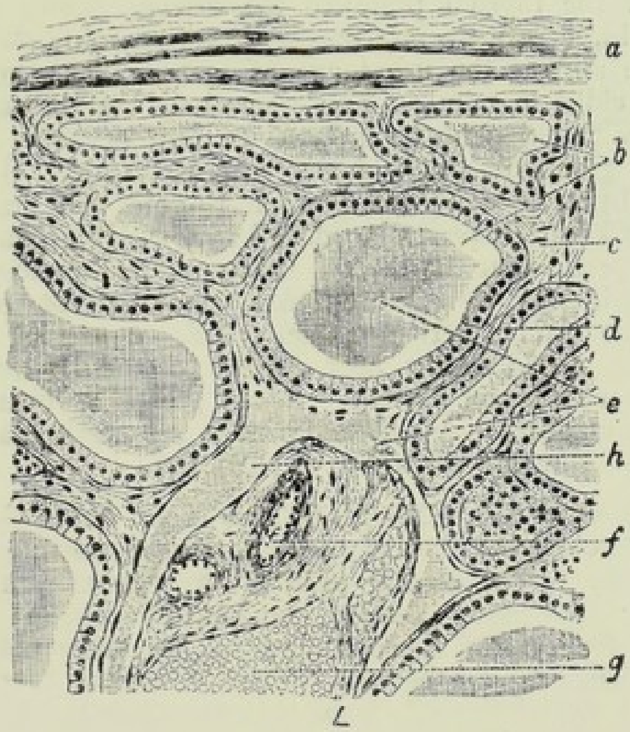

Fig. 64.—Part of a section of the human thyroid—*a*, fibrous capsule; *b*, thyroid vesicles filled with, *e*, colloid substance; *c*, supporting fibrous tissue; *d*, short columnar cells lining vesicles; *f*, arteries; *g*, veins filled with blood; *h*, lymphatic vessels filled with colloid substances. (After S. K. Alcock.)

THE SPLEEN.—This organ, present in all true vertebrates, is composed of a tissue closely resembling lymphoid tissue. It is well supplied with blood vessels and its cells come into closer contact with blood than those of almost any organ of the body, as lymph spaces are practically absent. The blood circulating through it passes eventually into the portal vein and so must traverse the liver before reaching the general circulation. It has been supposed that the function of the spleen is to pick out of the blood the red corpuscles that are the worse for wear and to destroy them, but the evidence on which this view is based is not convincing. Some have supposed the spleen to be the seat of formation of white blood corpuscles but this hypothesis rests chiefly on the fact that in some diseases, such as malaria in which the white cells of the blood are increased, the spleen is swollen. An animal deprived of its spleen suffers in no detectable manner. This however does not prove the uselessness of the organ as its duties may be taken up by other tissues, in fact, some of the lymphatic glands throughout the body have portions of their structure remarkably like the spleen in appearance, and it has been conjectured that these glands can undertake the spleen's duties, when this organ is removed.

THE THYROID GLAND.—This organ when microscopically investigated has a structure distinctly gland-like except that its acini are closed, that is, do not possess any duct. The acini are filled with a glairy fluid which may be a true secretion, and if so must be absorbed through the blood capillaries or by the lymph system. It is however a matter of doubt whether the thyroid adds something to the blood or whether it removes some poisonous product from the blood. The one thing certain is that in the majority of mammals removal of the thyroid is followed by muscular weakness, sluggish movement, and finally death. In man loss of the thyroid produces the disease known as myxœdema. The human child, bereft by any means of its thyroid, does not grow at the normal rate and at the usual age of maturity may remain a dwarf in body and a child in mind. The marvellous fact is that such a child (a *cretin* as it is called) may be induced to grow normally by administering the thyroid gland of any mammal with its food. Similarly young animals bereft by surgical means of their thyroid will grow normally if the thyroid of a kindred species is grafted in a suitable place in the body. It has been suggested that the thyroid manufactures hormones which regulate growth but it must be admitted that thyroid extract administered to an adult has the reverse action, namely, induces loss of weight. The thyroid gland is placed in the neck caudal to the larynx. It is very richly supplied with blood vessels. When greatly swollen it forms the tumour known as goitre. Associated with it are small glands called the para-thyroids the function of which is unknown.

THE SUPRARENAL GLAND.—This organ has a double origin in embryological development and displays a correspondingly twofold character in its tissue. The central portion, or MEDULLA, arises from the nervous system; the outer portion consists of columns of epithelial cells. Of the function of the outer portion we know nothing. As regards our knowledge of the medulla we are in a more favorable position. It has now been placed beyond doubt that the medulla of the gland produces and adds to the blood a hormone which can be obtained in crystalline form and which is sold in the market under various names such as *adrenalin*, *epinephrin*, *hemiscine*, &c. The chemical constitution of this substance has been determined; it is a derivative of the well known organic compound pyrocatechin. An extract of the suprarenal medulla, or adrenalin itself, if injected will produce all the effects of stimulation of the thoracic autonomic or sympathetic nerves. Thus the arterioles constrict, the pupil is dilated, the uterus contracts, the heart is accelerated, the movements of the alimentary canal are stopped, the hair is erected, &c. The intensity of the effect produced by even minute doses of adrenalin is surprising. Thus $\frac{1}{1000}$ grain injected into the blood stream of a dog may double the blood pressure owing to the powerful constriction of the arterioles as well as the local stimulating action on the heart. A dilute solution placed on a mucous membrane will so constrict the vessels that complete pallor results. The effects of such an injection or application are, however, very temporary. If the suprarenal glands be removed all those functions that depend upon thoracic autonomic stimuli fall into abeyance and there is also a marked muscular weakness and the animal invariably dies (Addison's disease in the human being). Adrenalin is largely used in medical and surgical science on account of its powerful properties. If it accompanies a local anæsthetic such as cocaine, when this is injected subcutaneously or intraspinally, it causes a much slower absorption of the drug. If given by the mouth it produces constriction of the blood vessels of the stomach and so delays the absorption of the poison, hence its use in emergency treatment. Injected into the blood it may tide over a crisis due to a dangerous fall of blood pressure. It will also stop the bleeding for a time of a raw surface and also, for a time, blanch an inflamed conjunctiva, &c.

THE PITUITARY BODY.—This organ placed in the skull at the base of the brain is also, like the suprarenal gland, of double origin and structure. A nervous part we have met already as an outgrowth from the thalamic region of the brain. The other part is epithelial in character. From the nervous portion an extract can be made which acts like adrenalin but with much less intensity. An extract of the epithelial portion is said by some investigators to increase the secretion of urine by the kidney. That this organ is important is seen by the consequences (or concomitants) of its disease, but of its functions we can say little.

THE THYMUS GLAND (True Sweetbread).—This organ, placed in the thorax in the young animal, undergoes atrophy when maturity is reached. A suggestion has been made that it undertakes duties in the way of hormone formation in youth that are afterwards carried out by the reproductive glands, but we are really quite ignorant of its significance.

APPENDIX

Classification of Carbohydrates

A. MONOSACCHARIDES.—According as these contain three, four, five, six, seven, etc., atoms of carbon in the molecule they are described as *Trioses* $C_3H_6O_3$, *Tetroses* $C_4H_8O_4$, *Pentoses* $C_5O_{10}H_5$, *Hexoses* $C_6H_{12}O_6$, *Heptoses* $C_7H_{14}O_7$, etc. The hexoses are, however, the most important. Hexoses $C_6H_{12}C_6$.

a. *Aldoses*, containing the group CHO peculiar to the aldehydes. There are several aldoses each existing in a dextro as well as a laevo-rotatory form (turning the plane of polarised light to the right or left). The chief aldoses are *dextro Glucose* (glucose, dextrose or grape sugar) and *dextro Galactose*.

b. *Ketoses* containing the group $COCH_2OH$ peculiar to the *Ketone-alcohols*. Each ketose can also exist in a dextro or laevo-rotatory form. The most important ketose is *laevo-rotatory Fructose* (levulose or fruit sugar).

B. DISACCHARIDES ($C_{12}H_{22}O_{11}$).—On boiling with delute acids or by action of special ferments a molecule of disaccharide takes up a molecule of water and forms two molecules of monosaccharides (hexose).

a. Saccharose (Cane sugar) + H_2O = Glucose and Fructose.

b. Maltose + H_2O = Glucose and Glucose.

c. Lactose + H_2O = Glucose and Galactose.

C. TRISACCHARIDES ($C_{18}H_{32}O_{16}$).—On hydrolysis the trisaccharide molecule gives rise to three monosoccharide molecules; thus Raffinose is split up into dextrose, levulose and galactose.

D. POLYSACCHARIDES $(C_6H_{10}O_5)_n$.—Hydrolytic agents convert these into disaccharides or monosaccharides, but the number of monosaccharide components in the molecule has not yet been determined.

a. Cellulose. b. Starch. c. Glycogen. d. Dextrine.

PHYSICAL CHARACTERS OF DEXTROSE ($C_6H_{12}O_6$).

Dextrose is a white crystalline solid. It is readily soluble in water, less soluble in alcohol, insoluble in ether. Its solutions rotate plane polarised light to the right.

CHEMICAL REACTIONS OF DEXTROSE.

a. Dextrose readily forms compounds with metallic hydrates in the cold, thus it dissolves cupric hydrate, giving a deep blue solution, and greatly increases the solubilty of calcium hydrate in water.

b. Aldehyde reactions.—

1. Dextrose in solution heated with metallic hydrates reduce these to the *ous* oxide or to the metal itself. If to a mixture of $CuSO_4$ and KOH some dextrose be added a rich red precipitate of cuprous oxide forms on boiling. Similarly bismuth subnitrate, alkali hydrate, and dextrose, when boiled together, will yield a black precipitate of metallic bismuth.
2. A molecule of dextrose will unite with two molecules of phenylhydrazine to form a molecule of *glucosazone* which crystallises in sheaves and is insoluble in water.
3. Glucose solution made strongly alkaline with alkali hydrate and boiled gives a brown colouration.

c. Molisch's reaction showing presence of carbon chain of at least four atoms. Dextrose solution treated with a small quantity of *alpha* naphthol and then strong H_2SO_4 gives a rich purple colour. This reaction is given by all carbohydrates.

d. Dextrose solution ferments readily with yeast.

Reactions of Levulose ($C_6H_{12}O_6$).

1. It dissolves cupric hydrate.
2. It gives the reduction tests. being a ketone alcohol.
3. It gives glucosazone on treatment with phenylhydrazine.
4. It ferments with yeast.
5. Boiled with excess of strong HCl it gives a rich vinous colour.

Reactions of Maltose ($C_{12}H_{22}O_{11}$).

1. It dissolves cupric hydrate.

2. It gives all the aldehyde reactions of dextrose. The compound with phenylhydrazine, called *lactosazone* is soluble in hot water and cryslises in radially arranged plates.

3. It ferments with yeast.

Reactions of Lactose ($C_{12}H_{22}O_{11}$).

1. It dissolves cupric hydrate.

2. It gives all the aldehyde reactions of dextrose. The compound with phenylhydrazine, called *lactosazone*, is soluble in hot water and crystallises in spherical agregates which, when magnified, look like wattle or mimosa blossom.

3. It ferments very slowly or not at all with yeast.

Reactions of Cane Sugar ($C_{12}H_{22}O_{11}$).

1. It dissolves cupric hydrate.

2. It does not give any of the aldehyde reactions of dextrose.

3. Boiled with a mineral acid and then neutralised it gives all the aldehyde reactions of dextrose owing to its inversion into dextrose and levulose.

4. It ferments with yeast.

5. Boiled with excess of strong HCl it gives a rich vinous colour owing to the setting free of levulose by inversion.

Levulose rotates the plane of polarised light to the left, but the other sugars mentioned rotate to the right.

Reactions of Starch $(C_6 H_{10}O_5)n$.

1. It is insoluble in cold water, but is soluble in hot, forming a colloidal solution which sets into a jelly on cooling.

2. It gives an intense blue colour on treatment with iodine; this colour vanishes on heating and reappears on cooling.

3. It does not give any of the aldehyde reactions of dextrose.

4. It does not ferment with yeast.

5. When boiled with mineral acid it is transformed into dextrose. The enzyme diastase transforms it into maltose.

Reactions of Glycogen $(C_6 H_{10}O_5)n$.

1. It is soluble in cold water, giving an intensely opalescent solution.
2. It gives a mahogany colour with iodine.
3. It does not give any of the aldehyde reactions of dextrose.
4. Boiled with mineral acid, it is transformed into dextrose.

Reactions of Cellulose $(C_6 H_{10}O_5)n$.

1. It is insoluble in water and dilute acids. It swells up with strong alkali. It is soluble in ammoniacal copper oxide.

2. If soaked in strong H_2SO_4 it is transformed in a few days into dextrose.

Reactions of Commercial Dextrine $(C_6 H_{10}O_5)n$.

1. It is soluble in cold water. giving a somewhat turbid solution.
2. Treated with iodine, it gives a purple or mahogany colour.
3. It does not give any of the aldehyde reactions of dextrose.
4. Boiled with a mineral acid, it is transformed into dextrose.

Fats.

Animal fats are glyceryl esters of the following acids:—*Butyric* $C_3 H_7 COOH$, *caproic* $C_5 H_{11} COOH$, *caprylic* $C_7 H_{15}COOH$, *capric* $C_9 H_{19}COOH$, *myristic* $C_{14} H_{29}COOH$, *palmitic* $C_{15}H_{31}COOH$, *stearic* $C_{17} H_{35}COOH$. In addition to these there is *oleic* acid $C_{17} H_{33}COOH$, which belongs to the acrylic series.

In animal fats triglycerides preponderate, and are named from the acid; thus we have *tripalmitin* or simply *palmitin* $C_3 H_5 (COOC_{15} H_{31})_3$, *tristearin or simply stearin* $C_3 H_5 (COOC_{17} H_{35})_3$, *triolein* or simply *olein*

$C_3H_5(COOC_{17}H_{33})_3$, etc. In addition to these there are, however, mono and di-glycerides, and also mixed glycerides in which the glycerin molecule is attached chemically to two or even three different fatty acids. Palmitin and stearin, which constitute the greater portion of animal fats, are solid at ordinary temperatures. Butter contains 6 per cent. of tributyrin, olive oil contains over 90 per cent. olein, lard contains approximately 60 per cent. olein.

Fats have a specific gravity below that of water; they possess a high refractive index; they absorb iodine, they are soluble in ether, chloroform, benzene, carbon disulphide, petroleum ether, and hot alcohol.

Fats can be hydrolysed by—

1. Superheated steam giving glycerine and fatty acids.
2. Sulphuric acid above 100deg. C., which forms sulpho-glycerides; these, when agitated with steam, hydrolyse readily.
3. Caustic alkali, giving glycerine, and alkali salts (soaps) of the acids.
4. The enzyme lipase.

Reactions of Stearic Acid.

1. It has the same solubilities as fats.

2. It dissolves in hot caustic alkali solution, giving alkali stearate or soap.

Reactions of Soaps.

1. Slightly soluble in cold water, readily soluble in hot water, giving colloid solution. If to a watery solution solid NaCl is added, the soap is thrown out of solution and forms a curd.

2. A hot aqueous solution of soap treated with H_2SO_4 gives alkali sulphate and free fatty acid, which floats on the top of the mixture.

3. Soap is soluble in warm alcohol giving a jelly on cooling.

Lipoid.

Cholesterin, properly *cholesterol*, $C_{27}H_{45}OH$, constitution unknown.

1. It crystallises from hot alcohol in white glistening plates with re-entering angles.

2. Soluble in ether, chloroform, benzene, hot alcohol, and oil.

3. Is laevorotatory.

4. Dissolved in chloroform and treated with strong H_2SO_4, a rich red is given in tne chloroform layer.

Isocholesterol $C_{27}H_{45}OH$.

1. Some solubilities as cholesterol.
2. Separates from hot alcoholic solution in jelly form.
3. Is dextroratatory.

In connection with these alcohols the following might be given :—

Phytosterol, probably the same empiric formula as cholesterol ; it occurs in all seeds and fruits, and is widely distributed in the plant kingdom. It crystallises from hot alcohol in bunches of needles.

Sitosterol, present in cereals ; it closely resembles cholesterol, but has a lower melting point.

The Phosphatides.—The simplest member of this series is *lecithin*, which consists of a glycerine molecule united with two molecules of fatty acid radicals, and, through a phosphoric acid group, with a molecule of *choline* $C_5 H_{15} NO_2$

Reactions of Lecithin.

1. Soluble in chloroform, benzene, oil, and alcohol ; sparingly soluble in cold ether.

2. Insoluble in water, but swells up and form an emulsion.

3. On saponification yields choline, glycero-phosphoric acid, and fatty acid.

4. Burnt in air, leaves a residue of phosphoric acid.

Phosphatides can be obtained readily from brain, soft roe (spermatozoa) of fishes, heart muscle, and egg yolk, which latter contains about 9 per cent. lecithin. Lecithin is frequently found combined with protein or carbohydrate, but whether the union is physical or chemical is undecided.

Cholesterol and iso-cholesterol form esters with fatty acids which are more resistant to hydrolysis than fats, and in consequence do not get rancid so readily. Wool fat, which constitutes 16 per cent. of Australian raw wool, when purified is known as *adeps lanae* ; this when mixed with water gives lanoline. Wool fat consists of cholesterol and iso-cholesterol and various esters of these. The lipoid of brain and nerve consist of phosphatides which are soluble in warm ether, but very sparingly soluble in cold ether, also cholesterol, lecithin, and other bodies not yet identified. Some of the constituents of lipoid are doubly refracting.

Proteins.

The exact chemical constitution of the proteins is unknown ; we cannot even assign to any of them an empiric formula. The molecular weight is large, being not less than 16,000. An approximate empiric formula has been suggested, namely—$C_{726} H_{1174} N_{194} S_3 O_{214}$. The phospho-proteins and the nucleo-proteins contain also the element phosphorus.

Proteins may be regarded as a condensation product of an immense number of amino-acids. In the condensation the NH_2 of one acid unites with the COOH of another, giving the linking group—CO—NH—CH_2—.

The chief amino acids are as follows :—

A. Mono-amino acids.

1. Glycocol or amino-acetic acid, CH_2NH_2COOH.
2. Alanine or amino-propionic acid.
3. Leucine or amino-iso caproic acid $C_5 H_{10} NH_2COOH$.
4. Phenylalanine or phenyl amino-propionic acid.
5. Tyrosine $C_6 H_4OHC_2H_4NH_2COOH$.
6. Cystine $C_6 H_{12} N_2O_4S_2$.

7. Aspartic acid or amino-succinic acid.
8. Glutamic acid or amino glutaric acid.

B. *Diamino-acids.*

9. Arginine $C_6H_{14}N_4O_2$.
10. Lysine or diamino-caproic acid $C_6H_{14}N_2O_4$.

C. *Heterocyclic compounds.*

11. Histidine $C_6H_9N_3O_2$.
12. Proline $C_5H_9NO_2$.
13. Tryptophane $C_{11}H_{12}N_2O_2$.

The mono-amino acids are amphoteric and have feeble acid and alkaline reactions. The diamino-acids and histidine are more markedly basic in character, and are precipitated by such reagents as phosphotungstic acid, potassio-mercuric iodide, tannic acid, etc.

REACTIONS OF UREA $CO(NH_2)_2$

Urea is the amide of carbonic acid. It is a white crystalline substance soluble in water and alcohol, insoluble in ether. It sublimes unchanged in vacuo.

1. It can be synthesised by warming ammonium cyanate.

2. When heated the crystals melt, liberating ammonia and a white sublimate; ultimately a white residue containing a number of bodies, including cyanuric acid, is left.

3. It can be saponified in solution by caustic alkali. $CO(NH_2)_2 + 2NaOH = Na_2CO_3 + 2NH_3$

4. It forms crystalline compounds with a number of acids, notably nitric acid.

5. Treated with nitrous acid, it yields nitrogen, carbon dioxide and water $CO(NH_2)_2 + 2HNO_2 = CO_2 + N_2 + 3H_2O$

6. It gives a white precipitate with mercuric nitrate.

7. On treatment with alkaline hypobromite, it gives a brisk effervescence of nitrogen $CO(NH_2)_2 + 3NaBrO + 2NaOH = Na_2CO_3 + 3NaBr + 3H_2O + 3N_2$

PURIN BODIES (Called Also Alloxuric Bodies and Xanthin Bodies).

They are precipitated from solution by ammoniacal silver nitrate. When heated they char.

1. *Uric Acid* $C_5H_4N_4O_3$ is almost insoluble in water; its salts, however, are soluble. Evaporated to dryness with nitric acid at a temperature not exceeding boiling point, and then treated with ammonia, it gives a magnificent purple. Salts of uric acid in solution can be precipitated by saturation with ammonium chloride; if acidulated with mineral acid they give a crystalline precipitate of free uric acid.

2. *Xanthin* $C_5H_4N_4O_2$ and *hypoxanthin* $C_5H_4N_4O$ are obtained chiefly from muscle.

3. *Guanin* $C_5H_5N_5O$ is a constituent of guano.

CONSTITUENTS OF MUSCLE.

1. *Paramyosinogen*, a globulin, coagulating at 50deg. C., precipitated by half saturation with ammonium sulphate. It is transformed slowly in solution into an insoluble clot.

2. *Myosinogen,* resembling the albumens, coagulates at 55-60deg. C., precipitated by full saturation with ammonium sulphate. It is transformed slowly in solution into an insoluble clot going through a stage called soluble myosin, when it is coagulated at 40deg. C.

The clot yielded by both these proteins is termed *myosin.*

3. *Nucleo proteins* present in small amount are derived from the muscle nuclei.

4. *Serum albumen* and *serum globulin* are derived from the enclosed blood and lymph in the muscle.

5. *Collagen* exists in the connective tissue framework. It is transformed on heating (cooking of meat) into gelatin.

6. *Extractives.*—

a. Creatin $C_4H_9N_3O_2$, which, when treated with mineral acid forms the anhyride creatinin $C_4H_7N_3O$

b. Purin bodies, especially xanthin and hypoxanthin.

c. Dextrorotatory lactic acid CH_3 CHOHCOOH.

d. Carbohydrates—glycogen and dextrose and intermediate products.

e. Inosite $C_6H_{12}O_6$, a carbocyclic body and chemically quite distinct from the sugars.

7. *Salts*—potassium phosphate is the chief ingredient of the ash.

Reactions of bile salts.

These are sodium salts of *glycocholic acid* and *taurocholic* acid.

1. On treatment with cane sugar and strong sulphuric acid, a magnificent purple is produced.

2. A very small addition of either bile salt to water lowers the surface tension in a very marked degree. If sulphur be sprinkled on pure water it floats, but if either bile salt be present it becomes wet and gradually sinks.

3. Bile salts in solution in water are capable of dissolving fatty acids, especially when these contain oleic acid.

4. Bile salts facilitate the digestion of proteins through trypsin.

Heat of combustion in gramme calories of various foodstuffs at constant pressure per gramme; reckoned as dry and ash free.

	Stohmann.		Berthelot.
Ethyl alcohol	—	...	7062
Glycerine	4316	...	—
Glucose	3743	...	3762
Levulo e	3755	...	—
Galactose	3722	...	—
Cane Sugar	3955	...	3962
Milk Sugar	3737	...	3777
Maltose	3722	...	—
Dextrin	—	...	4119
Starch	4183	...	4228
Animal fat	9500	...	—
Butter	9231	...	—
Vegetable oil	—	...	9520
Egg albumen	5735	...	5687
Meat, minus fat and extractives	5721	...	5728
Meat, minus fat	5641	...	—
Caseinogen	5858	...	5910
Uric acid	2741	...	2747
Egg yolk	5841	...	—
Urea	2537	...	2525

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