MANUALS OF ELEMENTARY SCIENCE

PHYSIOLOGY.

F. LE GROS CLARK, Esq.

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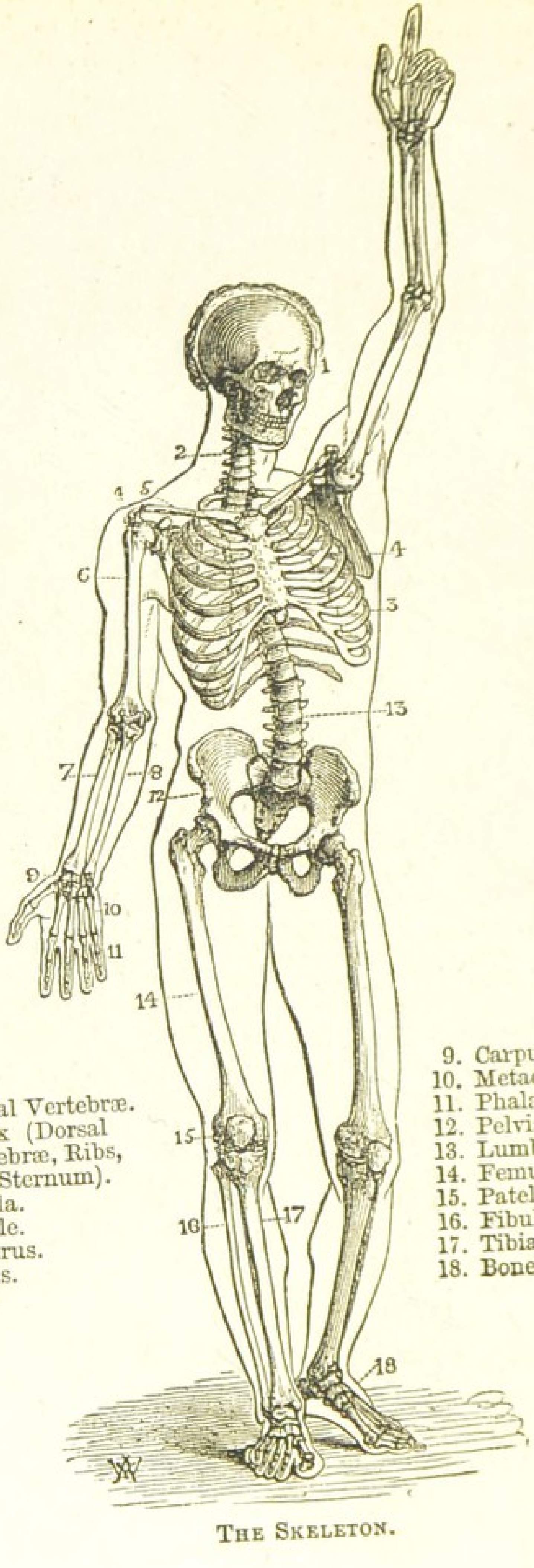

1. Skull
2. Cervical Vertebræ.
3. Thorax (Dorsal Vertebræ, Ribs, and Sternum).
4. Scapula.
5. Clavicle.
6. Humerus.
7. Radius.
8. Ulna.
9. Carpus.
10. Metacarpus.
11. Phalanges.
12. Pelvis.
13. Lumbar Vertebræ.
14. Femur.
15. Patella.
16. Fibula.
17. Tibia.
18. Bones of Foot.

THE SKELETON.

MANUALS OF ELEMENTARY SCIENCE.

PHYSIOLOGY.

BY

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In the interval which has elapsed since this Manual was actually sent to the press, such an advancing science as Physiology has necessarily made progress in many details, which, however, could not have been introduced into such an elementary treatise, and have no special bearing on the simple principles taught herein.

There is but one exception to this remark, in the step which has been lately taken towards determining the localisation of certain functions—especially those relating to the Muscular system—in the Brain. These observations are founded on experiment and Pathology, and will, no doubt, lead to further investigation of this interesting subject—(*See* p. 94).

March, 1874.

ELEMENTARY PHYSIOLOGY.

SECTION I.

VITALITY—ORGANISATION—DEVELOPMENT.

PHYSIOLOGY is called a *science* because it embodies a collection of general principles and ascertained truths relating to a particular subject; and it is further classed as a *natural science* because these principles and truths are founded on observation.

The word "Physiology" is derived from two Greek words, signifying a discourse about nature; but it is now employed in a more restricted sense, and constitutes the science of the various functions or uses of the constituent parts of any living body. Thus, there is animal physiology and there is vegetable physiology; and again the former is divided into human and comparative; or that which relates to man in particular, and that which includes a comparative review of the whole animal kingdom. The object of this elementary treatise is to teach some of the simple truths of Human Physiology; such as may be intelligible without any extended knowledge of other branches of science. Yet, it must be remembered that a more thorough study of Physiology cannot be undertaken without a considerable knowledge of other sciences; as, for example, mechanics, hydraulics, optics, &c., without which muscular action, the circulation of the blood, and vision, cannot be properly and fully understood. But it is hoped, by the avoidance of technical terms when possible, and their definition when essential, and also by a familiar explanation of any natural law which may be referred to, that there will be no material difficulty in understanding the simple principles and details which will be taught in these pages.

Whenever a piece of mechanism, designed for some particular use, is brought under our notice, and we wish to understand its manner of working, we naturally inquire about its structure; for without some knowledge of how its component parts are put together, and by what power or means it is set in motion, we cannot hope to understand how it performs the part which we see that it does.

Such is the case, for instance, with a watch or a steam engine: their mechanism is distinct, according to their respective requirements, and must be studied carefully in order to be understood; and the moving power in each is also very different—in one being dependent on the uncoiling of a spiral spring, and in the other being due to the expanding property of water when converted into steam. In like manner, living bodies manifest certain changes, and their component parts perform many functions under the controlling influence of a power which is known as vitality or life.

Thus, it will be observed, from what has been said, that it is impossible to study the uses of various parts of the body, without some knowledge of their structure; and this branch of knowledge is Anatomy. Therefore, some reference will necessarily be made to the anatomy, or structure and relations, of different parts or organs, when speaking of their functions or uses.

In order to learn Anatomy, the parts or organs to be displayed must be dissected. As the three words employed in this statement will often recur in these pages, it will be well at once to define their meaning, and also to explain, as far as may be, what is meant by vitality or life.

The words "anatomy" and "dissection" have the same meaning, the former being derived from the Greek and the latter from the Latin words, signifying to cut apart or separate. But anatomy is employed to signify the science of structure in living bodies; and dissection is used to denote the unravelling or display of parts of the body by means of which anatomy is studied.

It is so convenient to use the word "organ," as well as "organisation," which is derived from it, and the corresponding verb, "organise," that the student should at once understand what they mean; and this will be readily accomplished by some examples or illustrations. The word "organ" signifies some part or parts of the body which have a particular use: thus, the muscles are the organs of motion, the nerves the organs of sensation; the eye is the organ of sight, and the heart and blood-vessels are the organs of circulation. Again, any structure is said to be organised or to have organisation which possesses the properties by which a living body is distinguished from one which never had life. Therefore, we speak of the organic world as distinguished from the inorganic; the former including organised or living bodies, and the latter the stones, metals, and other ingredients of which the earth is composed.

But what is the vital or living principle by which the organic world is distinguished? in other words, What is life? In order to understand what is known or believed on this interesting subject, it will be necessary to say a few words about the agencies or "forces," as they are termed, by which various changes in the inorganic world are brought about. These are called "physical forces," and include light, heat, electricity, and various chemical agencies. Now, there can be no doubt that very many of the changes which occur in the living body are due to these forces; and some physiologists have been disposed to believe that all vital changes are caused by the agency of physical and chemical force, in obedience to a law that one force may be converted into another; although they admit that the present state of our knowledge does not afford a satisfactory explanation of all vital actions in accordance with their theory or belief. Whereas others, who have carefully examined this subject for themselves, still maintain that life is a distinct and independent endowment, which cannot be originated by any combination of physical force, nor imparted except by inheritance. In this work it will be assumed, in the absence of any satisfactory proof to the contrary, that life or vitality is a distinct endowment, capable of propagation, and expanding with growth, so as to pervade all the component parts of the body, and to influence various changes which take place in accordance with physical laws; its extinction leaving those laws to work out their natural consequences, as in the inorganic world. At the same time it may be observed, that the hypothetical explanation of vitality referred to is in no way inconsistent with the operation of creative power as made known to us; which is characterised as much by the simplicity of the agents employed, as by the complexity and magnitude of the results obtained.

How is a living body distinguished from inorganic matter, incapable of life? It is neither from its possessing a definite form, nor from its being capable of growing; for such is the case with any mass of crystal, which increases in size by the addition of new crystals. But when we examine the component elements, as they are termed, of an organised body, we find they are more numerous and complicated than in inorganic bodies; and the manner of increase of a living body is not by simple addition to its bulk externally, but by the growth or development of each individual part which composes the whole. Further, and most importantly, the organised living body springs from a parent body, and this is the only mode in which it originates, or in which its existence is perpetuated.

It has been remarked that, when life is extinct, various chemical changes take place in an organised body, by which it is dissolved, and its component elements are distributed. This, too, is another distinctive characteristic, viz., death. But decay and dissolution are not limited to the closing scene of life. This form of death is constantly going on in the living frame, and is, in fact, essential to the continuance of life in the whole. Fresh material is constantly supplied as the old is worn out; and thus there is a continual change going on in every part of the living frame. For a certain time the supply is in excess of the waste, and then there is growth; and after a certain period of maturity is passed, decay is in excess of supply, and then the living fabric gradually wears out, and ultimately dies.

The distinction between the lowest forms of animal life and vegetable life is very ill defined. The most marked, probably, is the capability of the latter to draw its supply of nutriment from inorganic matter; but it is unnecessary to pursue this subject further. Before proceeding, it will be requisite to consider briefly what are the materials from which the living fabric is built up.

There seems no reason to believe that, since the creation of the earth, there has been any addition to or abstraction from its component parts, unless, indeed, we except aërolites. Many changes preceded the condition which fitted it for the habitation of man, and changes are continually going on around us and in us. As there is no new creation, so there is no loss of matter or annihilation; one generation of living beings succeeds another, and the same elements provide for the growth and development of each, until they pass away to give place to others.

It has been the business of chemistry to ascertain what are the various ingredients of the earth and its atmosphere, by resolving them into what are termed elemental substances or elements. By the word "element" is meant that which cannot be resolved into any simpler form. If we take, for example, a piece of chalk, we find that it can be divided by chemical action into a gas called carbonic acid, and lime; therefore it is known that chalk is a compound body. But if we take a piece of metal, gold or silver, for example, no chemical process can resolve it into a simpler form, and this is therefore called an element.

There are more than sixty elementary substances, and a great many of them are found more or less abundantly in the human body. It is scarcely necessary to remark that, as the elements which compose an organised body are derived from inorganic matter originally, they are all, without exception, found in the latter; and the special conditions under which they exist in the former, and which are chiefly due to the all-pervading principle of life, constitute the real and only difference in the two cases. Therefore, it will be readily understood how naturally these elements disperse and enter into new combinations as soon as life is extinct; and also during life, whilst waste is going on, and the never-ceasing loss is supplied by new material.

Seventeen elements have been discovered in the human body; but three of these are probably accidental, and many others exist only in small quantities. Four of these elements are gases, and constitute by far the largest proportion of the human body, viz., oxygen, hydrogen, nitrogen, and chlorine. Of the solid elements, calcium, potassium, sodium, and carbon are most abundant; whilst phosphorus, sulphur, magnesium, iron, silicon, and fluorine exist in smaller quantities. Other elements, as already remarked, may be found incorporated with different organs occasionally, being introduced accidentally with the food or drink.

These different elements are variously combined to form compounds, of which water is the most abundant, for it forms more than two-thirds of the weight of the entire body: water is a compound of oxygen and hydrogen. The other chief *organic* compounds are the *albuminous*, of which the albumen, or white part of an egg, is a typical example. These exist in various forms, and are constituted of oxygen, hydrogen, nitrogen, and carbon, the last being most abundant. The *gelatinous* or jelly-like compounds, including cartilage or gristle, consist of the same elements as albumen.

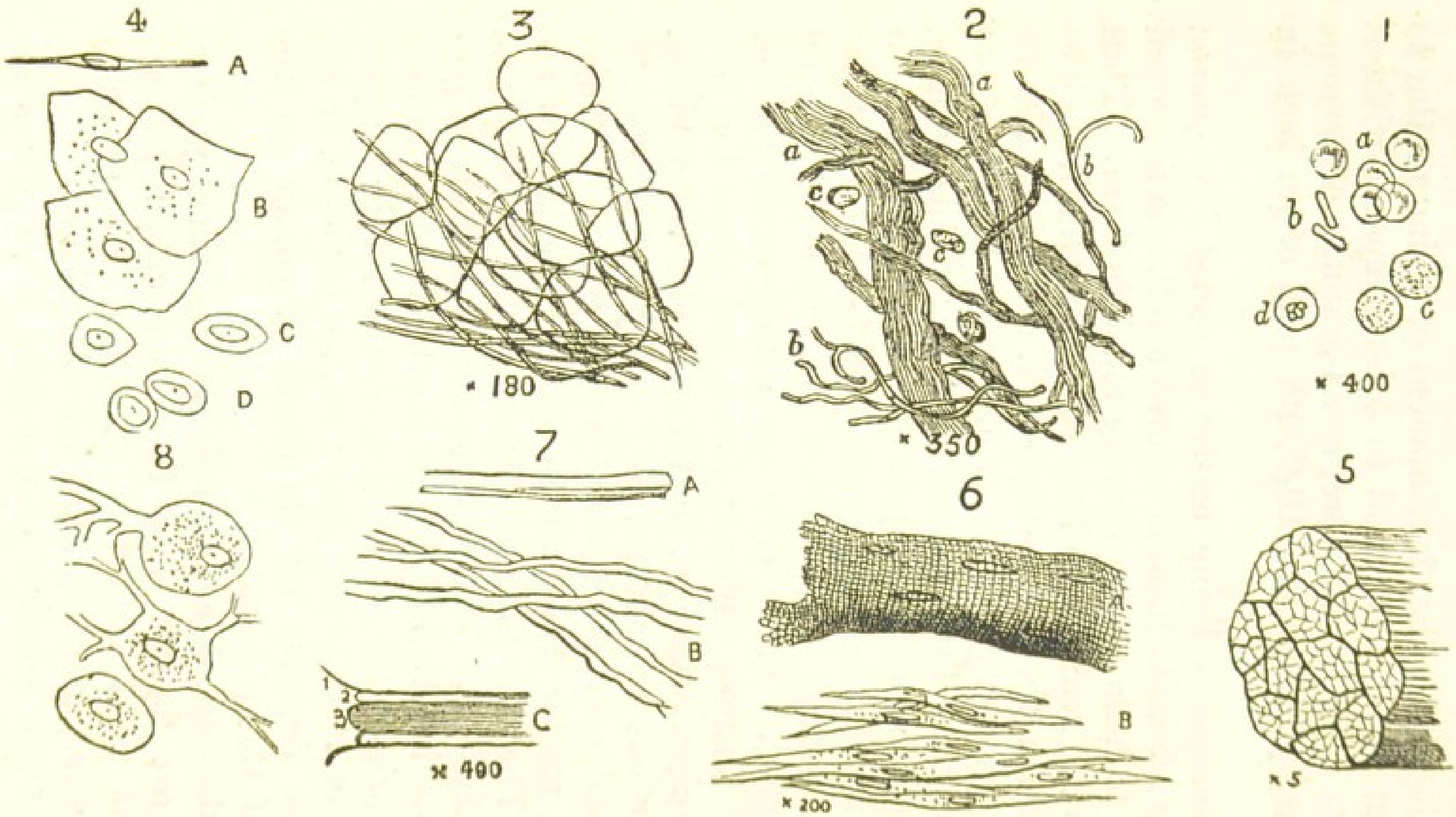
Oleaginous, or fatty compounds, contain three of the above ingredients, but no nitrogen. *Saccharine*, or sugary compounds, are constituted of the same elements as the last.

In tracing back the development of living matter to its simplest form, it is found to exist as specks without any definite form or structure, or as granules of extreme minuteness, perhaps the 10,000th part of an inch in diameter.

This elementary living matter is called *Protoplasm*. Its simplest definite form is termed a cell, and this word is applied to little bodies varying much in form. Thus some cells are really little bags containing fluid, such as those in which the fat is deposited, and which will be described presently. Other cells—so called—are not hollow, but like little masses of jelly; whilst others, again, might more appropriately be named discs or scales, being flattened; they are of different consistence and form, though still marked by the same general characteristics. These cells are witnessed in various parts, and assume different forms and characters according to circumstances; as, for example, in the blood, cuticle, mucous membrane, &c. They are universally diffused, and may be regarded as the primary form of organised matter from which elementary tissues are formed. They are themselves formed from protoplasm or by subdivision. Wherever colouring matter, or pigment, exists in the body, it is in the form of minute particles, principally of carbon, contained in varying quantities in transparent cells; as, for example, in the skin, which depends for its depth of colour on the quantity of this pigment.

Out of the organic compounds the ingredient parts of the body are formed, and these are called primary tissues, the most important of which are severally named, fibrous, muscular, and nervous tissues.

Fibrous tissue consists of fine threads or fibres arranged in various ways to adapt each form for its special uses. Some are inelastic, as those which form the



1. Blood Corpuscles.
2. Areolar Tissue.
3. Fat.
4. Epithelial Cells.
5. Muscle—fasciculi.
6. Ultimate Fibre of Striped Muscle, and cells of Unstriped Muscle.
7. Nerve Fibres.
8. Nerve Cells.

ligaments that bind the joints together and connect muscles to bones; others are elastic, as in blood-vessels and other parts requiring this property. Fibres of a mixed character are found abundantly in almost every part of the body, forming a net-like web, and constituting a connective tissue between different textures; as between the skin and deeper parts, and between the muscles. The *fat* is deposited in little cells situated in the meshes of the connective tissue.

Muscular tissue forms the great bulk of the frame, and is usually recognised as "flesh." It is arranged in large bundles of fibres which are held together by connective tissue; and these again are made up of smaller bundles. If the delicate filaments of which these bundles are composed are examined under the microscope, they are found, in some muscles, to have cross stripes upon them; but in muscles which are not under the influence of the will these cross markings are, for the most part, absent. Muscle is universally needed, as will be exemplified hereafter.

Nervous tissue exists in organised bodies, to superintend the proper performance of the functions of life. It is accumulated in masses in certain parts of the human body, especially in the skull, where it forms the brain, and here it consists of minute granules or vesicles, which are called *nerve corpuscles;* or it is spread out in delicate fibres, or rather tubes filled with nerve-matter, packed in parallel bundles, and these are called nerves; they communicate between the central mass and the organs supplied with nerve-force.

Development.—The development of vegetable and animal bodies is identical in principle; there are those conditions we call vitality, which exist and are ready to be called into activity under favouring circumstances. The seed, which is to the plant what the egg is to the bird, consists not only of the germ, but of nutrient matter surrounding it, by which the germ is nourished, when the conditions requisite for its development are present. In this way the nutrient exterior apparently decays, whilst it is really nourishing the germ; afterwards the germ is enabled to draw its nutriment from without. In the bird's egg, the nutrient material is abundant, and suffices to supply what is needed for the chick till it burst its shell.

The conditions referred to are, specially, warmth and moisture. These are supplied by the sun and rain in the case of the plant, and in the case of the egg by its contents and the mother's warmth. These agents prepare the elements contained in the nutritious material for new combinations, by which the germ may be built up; and this is regarded, as already remarked, by some physiologists as a conversion or transformation of physical forces into vital power. After birth the external relations of the being are changed, but development is still continued on the same principle, although under different circumstances.

SECTION II.

THE SKELETON.

The highest division of the animal kingdom is distinguished by having a back-bone or spinal column, and thence called "Vertebrate;" and again, the highest class in this division consists of those animals which suckle their young, and are, therefore, called "Mammalia." At the head of this class Man stands alone, because, as regards his outward form, he is the only mammal which stands erect, using only two of his limbs for support, and having two hands at perfect liberty for other purposes. But, in many other respects, man is pre-eminent. His head is poised on the summit of his spine, and his body is so placed in relation to his legs, that he is able perfectly to balance himself, on each alternately, in walking and running. His senses, though individually less acute than those of some animals, possess greater variety and delicacy of perception. His large thumb, which he is able to move so freely and in such a variety of directions, is most valuable to him by his being able to oppose or bring it into relation with any of the fingers, as in handling a pen or a needle, or in wielding a sledge-hammer. His face does not project, or but little so, beyond his forehead; and the whole of his brain-case or skull is capacious, because his brain is large in proportion to the rest of his body;—a peculiarity which is evidently associated with his superior intelligence.

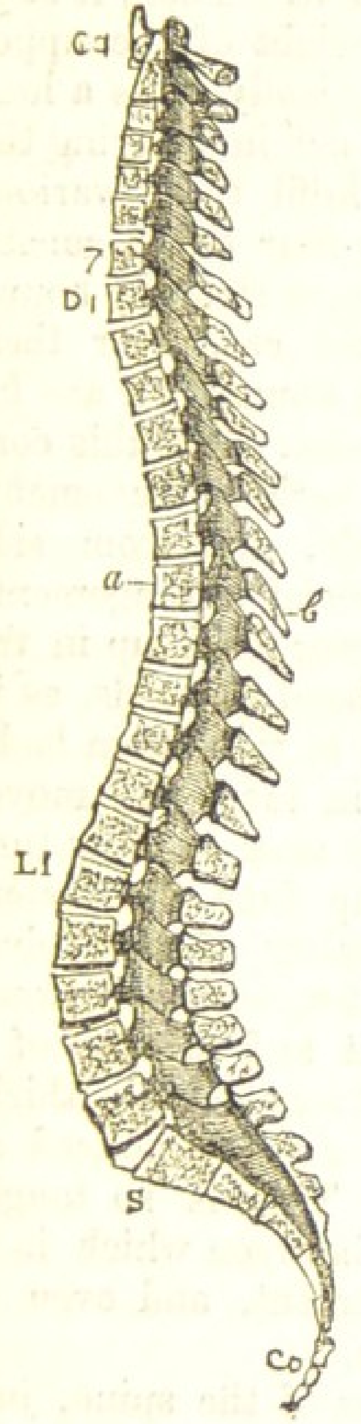
BONE.

The appearance of *Bone* is familiar to every one; it is hard and, to a certain extent, brittle. If a piece of bone be carefully burnt, and afterwards examined, its brittleness will be found very much increased; in fact, it will then readily crumble if pressed between the thumb and finger. But if a piece of bone be put into some strong acid solution, say muriatic acid and water, it loses its brittle property altogether, and can be bent in different directions without breaking. From these experiments we learn that bone consists of two entirely distinct parts, one of which is the organised living part, and the other, an earthy matter—bone-earth—which is lodged in the form of small particles, principally of phosphate of lime, in the firm but elastic animal matter which gives its form to the bone. The animal part of the bone, being combustible, can be burnt out in the fire, leaving the earthy part; and the latter can be dissolved in acid, which does not act on the animal part. The earthy matter, by weight, much exceeds the animal, being in the proportion of 67 to 33. Bone is an organised texture, *i.e.*, possessing blood-vessels and nerves, and therefore endowed with the power of self-repair when injured. Its properties are such as to qualify it in an admirable manner to fulfil the various offices assigned to it. But sometimes we find that there is either a deficiency or an excess of one or other of the constituent parts of bone; and then one of its chief uses is imperfectly performed: as the bone may break readily; or it may bend under the weight thrown upon it, as is seen in rickets, in which the legs are chiefly affected. A section of bone shows the canals through which the blood-vessels run, which nourish it.

The uses of bone are for protection, support, and leverage. Thus, the bones of the skull and chest protect the brain and lungs; the bones of the thigh and leg support the weight of the body; and the long bones of the body and of the limbs constitute a number of levers, upon which the muscles act in various movements.

Having these different offices to perform, we find that bones vary much in shape; some being broad and flat, others long and cylindrical, and a large number very irregular in form. The flat bones have a number of cells or meshes in their interior, between two hard surfaces. The long bones, such as those of the leg and arm, are hollow inside, with a cell texture like that of the interior of flat bones, and filled with an oily marrow; their ends are spread out to form the joints. The irregular bones are chiefly those of the spine, wrist, and foot; they consist almost entirely of cell structure, or, as it is called, *cancellous* texture. There are special and satisfactory reasons why these peculiarities of structure should exist. In the flat and irregular bones, where an expanded surface is necessary, the cancellous texture exists to afford such surface with as little increase of weight as possible. The same remark applies to the expanded extremities of long bones. But the principle is much more completely carried out in the central length of those bones, the hollow or cavity within diminishing the weight of the bone very materially, without detracting from its strength.

In birds there is a remarkable arrangement existing to fit them for flight. The outer shell of their limb bones is hard and thin, and therefore they are light; the cell texture



SECTION OF SPINAL CANAL,
Showing general construction of Vertebræ, and curvatures of Column.

C 1. 1st Cervical Vertebra.
D 1. 1st Dorsal.
L 1. 1st Lumbar.
S 1. 1st Sacral.
co. Coccyx.
a. Body of Vertebra.
b. Spinous Process.
c. Canal.

within is scanty; and instead of marrow existing there, air is admitted into the bones by passages communicating through air-sacs with the lungs. Thus, as the blood in birds is many degrees warmer than that of quadrupeds, the presence of the heated air in their bones assists materially in diminishing the gravity of the bird relatively to the surrounding atmosphere, and thus enables it more easily to sustain itself in flight.

The *Spinal column*, or backbone as it is commonly called, is a marvellous piece of mechanism, combining many offices, which nothing short of perfection in mechanical arrangement could enable it to accomplish. It consists of twenty-four bones piled one on the top of another, and each bone has a central hole, so that when all the *vertebræ*—such is their name—are put together, there is a long canal extending from the top to the bottom, and communicating with the interior of the skull by an aperture in the centre of its lower part. The services required of this long column, thus built up of many pieces, exemplify all the uses to which bone is put; it protects the delicate spinal cord or marrow, which is a prolongation of nervous matter from the brain, and which is so essential to life, that death almost always follows any serious injury to it. Then, it supports the head, and transmits the weight of the upper part of the body to the legs; and, lastly, it is a long lever upon which powerful muscles act in swaying the body in different directions. To fulfil these various offices, it is evident that the twenty-four bones constituting the spinal column must be very strongly bound together; and such, in truth, is the case: for their connection is so firm that the bones themselves are far more readily broken than torn asunder. Yet this connection is such as to admit of the various movements of bending backwards and forwards, and from side to side; moreover, there are special arrangements of a still more complicated character high up in the neck, to permit of our bowing the head forwards, as in nodding, or of turning it from side to side, as in looking over either shoulder; in fact, in the latter movement, the head and first bone of the neck actually turn on a central pivot which springs up from the second vertebra. This strength and mobility of the spinal column are specially due to the interposition between each two vertebræ (except the first and second) of a very strong and elastic texture, of considerable thickness, and composed of the tissues already noticed as the elastic fibrous, and cartilage. This is so tough, and clings so firmly to the bones between which it is attached, that it permits of movement, and even of severe wrenches, without being torn.

But even beyond the special uses of the spine, just described, there is another important one which requires notice, and that is, that its construction is designed to break the effect of shock to the brain. In order to understand this, it is necessary to bear in mind what has been already said about the elastic pad between each two adjoining vertebræ; but also it should be known that the column is thrown into curves; two smaller, one above and the other below, with their convexity directed forwards, and one large one with its concavity forwards in the centre,—the latter, by its extent, being equivalent to the former two,—so that the centre of gravity is not disturbed.

It will not be difficult to understand that every time the foot is planted firmly on the ground, and still more in running or jumping, the shock is conveyed upwards to the under part of the skull, which rests on the top of the column. But under these circumstances the elastic connecting pads and the curves both yield, and thus the shock is broken. Yet it is so important that this shock should not be felt, that there is a further provision for the same purpose, which will be noticed presently, in the form and mechanism of the foot.

All along this column, and between each two adjoining bones, there are holes on either side for nerves to pass out from the spinal cord, to be distributed to various parts. Near to these holes the ribs are attached (3) * ; they consist of twelve pairs, which increase in length to the widest part of the chest, and then again diminish. The ribs are movable, but the mode and use of their movements will be noticed hereafter with the apparatus for breathing. In front the ribs are attached to the breast-bone or *Sternum* by cartilage, and this long flat bone forms a shield to the front of the chest.

The spine rests below on the upper part of a wedge-shaped bone, called the *Sacrum*, and this is fixed or wedged in between the two hip-bones, the *Ossa Innominata ;* this pair of bones, together with the central wedge-shaped bone, form the basin or *Pelvis* (12), in which rests the lower part of some of the organs concerned in digestion of the food and other offices connected therewith. The Pelvis is very strong and massive, and it is needful it should be so, for it has to transmit the whole weight of the body and head to the lower extremities. The three bones are firmly knit together by cartilage and ligaments, so as to allow of no movement whatever between them. The rim of this basin may be distinctly felt, where it forms the hips; and the body

* See Frontispiece.

rests, in the sitting posture, on the rough prominences which constitute its lowest part. On either side it presents a deep cup, the *Acetabulum*, in which the head of each thigh-bone plays, the two forming the hip-joints.

The upper limbs, or *Extremities* as they are usually called, consist of many parts, which are severally named the Shoulder, the Upper arm, the Fore-arm, and the Hand. In the shoulder there are two bones, viz., the blade-bone or *Scapula* (4), and the collar-bone or *Clavicle* (5). The blade-bone rests loosely on the back of the chest, being connected to it only by muscles. One of its prominences, which forms the point of the shoulder, is attached to the outer end of the collar-bone by strong ligaments; and the inner end of this last-named bone, which is curved like the letter S, is connected very firmly to the upper part of the breast-bone. The little hollow spot, which may be felt at the upper part of the breast-bone, is all the space that separates the inner ends of the clavicles from each other. The special purpose which is answered by the loose relations of the blade-bone is, that it may follow the upper arm in its more extended movements, and thus greatly increase its sphere of motion, of which the joint between the collar-bone and the breast-bone is the centre or pivot. As regards the collar-bone, though small, it is a very important bone, for it supports and gives breadth to the shoulders, and thus adds very materially to the usefulness of the arm and hand. It exists in some only of the lower animals, such as use their anterior extremities for other purposes than merely walking, as in climbing and catching their prey.

The upper arm consists of one bone only, called the *Humerus* (6), which corresponds to the thigh-bone in the lower extremity. The cup, in which the head of the humerus is lodged to form the shoulder joint, is at the upper and outer angle of the blade-bone, and is of an oval shape and very shallow, whereas the ball which fits into this socket forms half a sphere. No one examining these two surfaces together for the first time would suppose that they could belong to each other. But a more careful study of the mechanism of this interesting joint explains this peculiarity of its shape.

It has been already remarked that great freedom of motion is requisite in the shoulder; at the same time it is no less important that there should be security against the arm-bone being thrown out of its socket. A comparatively simple arrangement would ensure either of these requirements separately; but the difficulty consists in securing both together, as they are so opposed to each other. Now, we know that a miracle is not performed to reconcile mechanical inconsistencies; therefore, we find simply that the very best means exist which could be devised under the circumstances. This joint is as perfect as the difficulties to be surmounted can make it, yet it is more liable to dislocation than any other in the body.

In comparing the corresponding bones and joints in the upper and lower extremities—a course which is selected as the more instructive—we find that, although there is such a marked contrast between the pelvis and shoulder, the other divisions of either limb resemble each other very closely. The large head of the thigh-bone, or *Femur* (14), is lodged in a deep socket, where it is held by a strong round band of fibres, passing from one surface of the joint to the other, and also by other strong ligaments and muscles. The movements permitted by this joint are as various as, but far more limited than, those of the shoulder. The centre or shaft of the thigh-bone is both longer and stronger than that of the arm-bone. Each is expanded below to form part of the hinge-joints of the elbow and knee;—joints in which there is very little movement except in one direction, like a hinge. The knee-pan or *Patella* (15), in front of the leg, corresponds to the point of the elbow; but the former is a separate bone, and the latter forms part of one of the bones of the fore-arm. In describing the remainder of the two limbs, it is necessary to remember that the entire front of the one corresponds to the back of the other, just as the palm of the hand corresponds to the sole of the foot.

The two leg-bones, called *Tibia* (17) and *Fibula* (16), are placed side by side. The former is much the larger, and the latter is often called the splint-bone, from its constituting a side support to the tibia. The smaller bone does not form part of the joint at the knee, but it acts as a prop to the under part of the head of the larger bone. In the arm the two corresponding bones are of more nearly equal size, though the outer one, on the thumb side, is often called the small bone; but this, the *Radius* (7), is not, in reality, much smaller than its fellow, the *Ulna* (8). Indeed, at the wrist it is larger and the more important of the two, because it is joined to the wrist-bones, almost to the exclusion of the ulna. But at the elbow joint the latter bone is much more expanded, and forms the large prominence at the back of the joint, commonly called the point of the elbow, upon which we rest the arm. In the hinge movements of this joint the radius moves with the ulna. There is, however, a remarkable contrast in the form of the bones of the arm and leg, to admit of the special movements required of the former; for, whereas the leg-bones always hold the same relation to each other, being in this respect immovable, the radius is so connected to its fellow, the ulna, that it can be rolled round the latter in whatever position the arm may happen to be. And now we understand why the radius is small and subsidiary at the elbow, and is large and important at the wrist; it is in order that it may not impede, nor be impeded in, the hinge movements at the elbow, whilst it may carry with it the hand, as it rolls round the ulna. These rolling movements in either direction are called *pronation* and *supination;* the former is when the hand is rolled round so that the palm is directed backwards, the latter when this is reversed.

The wrist and ankle joints are, in some respects, alike, but in others very dissimilar. The points of contrast are, of course, associated with their several uses—the hand requiring great freedom of motion in various directions, and the joint with the foot being necessarily more firm and strongly bound together to receive the weight of the body. In both, the hinge movements are the chief; but both also admit of movement from side to side. The utility of this latter movement in the hand is obvious; but it is not so evident in the foot, until we consider the importance of such yielding of either side of the foot, when we tread upon an uneven surface. If it were not for this yielding motion, sprains would be more frequent; but, as the ankle accommodates itself to the inequalities on which the foot presses in walking, it is not sprained until it be twisted so far as to stretch or tear the strong bands which form the lateral ligaments of this joint, and which extend from the lower points of either bone of the leg—the *Malleoli*—to the foot. These points of bone overhang the joint on either side, and serve materially to protect it from injury.

The component parts of the hand and foot correspond. They consist severally of the wrist-bones or *Carpus* (9), and of the instep-bones or *Tarsus* (18); of the *metacarpal* (10) and *metatarsal* bones, each five in number; and of the fingers and toes proper, each being composed of three bones, the *Phalanges* (11), except the thumb and great toe, which have but two. The wrist-bones, eight in number, form a front arch or hollow, from side to side, in which the tendons and vessels and nerves are lodged as they pass to the hand. The arrangement of the bones of the foot, including the seven bones of the tarsus, in a double arch—one from side to side and the other from before backwards—answers the same purpose, but also fulfils a more important design, that of forming a spring, so to speak, on which the weight of the body is received; this is accomplished in the following way:—The double arch, which has just been mentioned, rests on the firm basis of a tripod; viz., upon the heel behind, and upon the ball of the great toe and that of the little toe in front; an arrangement which admirably fulfils its design, when it is not spoiled by raising unnaturally the back point of the tripod, and thereby disturbing at once the spring of the arch and the centre of gravity. Then the tarsal bones are connected to each other and to the metatarsus by two joints, admitting of a yielding or gliding motion over each other. Thus, when the weight is transmitted, with a varying momentum, from the body to the foot, as in walking, running, or jumping, it is received upon the top of this spring arch, which yields, and thus the shock is broken and the effects of the counter shock are in great measure escaped. This arrangement, therefore, aids the curves and elastic connecting structure of the vertebral column, in preserving the brain from injury in violent falls on the feet.

The peculiar development and power of the thumb has been already alluded to. Its metacarpal bone moves freely on the wrist, and it can thus be applied readily to any one of the fingers, being supplied with many muscles for the purpose of its varied and many movements. It is wonderful to contemplate how much has been accomplished by this little piece of mechanism, how truly civilisation is dependent on this minister of the designing brain of man, whose intelligence would be shorn of its practical fruits without the aid of this, the instrument alike of toil and necessity, and of all the refining arts which are so interwoven with our social happiness and enjoyment.

It remains now to consider the *Skull* or brain-case and the *Face*. The bones of the skull and face are intimately connected together, some of them being common to these two divisions of the head. The vaulted cavity in which the brain is lodged is chiefly composed of four bones, one in front, which forms the forehead, the *Frontal* bone, one behind which forms the back of the head, the *Occipital* bone, and a pair, one on either side, the *Parietal* bones. Besides these, there is the bone of either temple, the *Temporal* bones, and a large space below in the centre of the skull inside, is filled by an irregular bone, called the *Sphenoid*, and a smaller one which also forms part of the nose, the *Ethmoid*. The sphenoid connects the frontal and occipital bones together, and also forms a common bond between them and some of the bones of the face.

The face is the special seat of the senses, and its form is, to a considerable extent, moulded in conformity with this use. But it is also the inlet for the food; and the grinding apparatus, by which the harder forms of aliment are reduced before their introduction into the stomach, is also an important constituent part of the face, though less so in man than in many of the lower animals. The chief bones are those of the jaws; the upper being divided into a pair, joined in the centre, and forming the greater part of the palate, as well as of the nose, and a part of the socket of the eye. The *lower jaw* is a single bone, and moves in two sockets in the temporal bones, being raised and depressed and moved from side to side in masticating the food; a subject respecting which more will be said by-and-by. The *nasal* bones are a small pair, but prominent; and the cheek bones, *malar*, project below and behind the eye-socket or orbit. The special characteristics of the bones of the human face are, the prominence of the nose and of the centre of the lower jaw or chin. Other peculiarities associated with the senses will be noticed in their proper places.

The mechanism of the skull-bones is an interesting study. The delicacy and importance of the organ they contain necessitate great power of resistance to external violence, and we find every arrangement conducing to this object. The arched form of the skull is that which is best calculated to fulfil this purpose; then the bones are connected together by a zigzag line of union which renders their separation almost impossible. But in noticing still more closely the texture of the bone in different parts, this adaptation of mechanical relation to variation in texture becomes signally manifest. It has been already remarked that the skull-bones consist of an inner and outer layer, with a cell-texture between them. Now these layers are very different in respect of one quality; the outer one being tough, the inner much harder and brittle; conditions which are associated with their resisting power to blows and shock. The outer and tough layer in adjoining bones is united as the joiner would connect his work, viz., by dovetailing the edges together; but the brittle layer could not be so treated, and is, therefore, united by adaptation, as the worker in marble would unite his work.

SECTION III.

THE JOINTS.

The *joints* have been incidentally alluded to in the description of the bones, but they require a brief, separate notice.

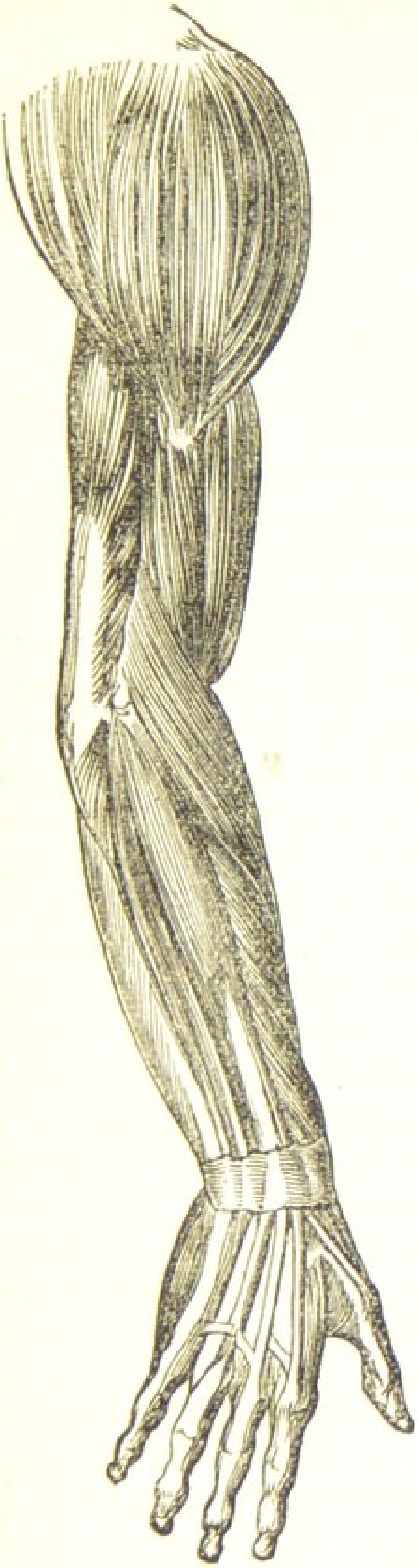
The presence of a joint or junction between two bones does not necessarily imply motion; and this circumstance has given rise to the division of all joints into movable and immovable. The former are represented by the joints of the long bones in the limbs, and many besides; the latter by the junction of the bones of the skull, pelvis, and others. In some of the fixed articulations the bones come into contact, as in the skull; in others fibrous texture and cartilage, *i.e.*, fibro-cartilage, is interposed: this is the case in the connection between the bodies of the spine-bones, where movement is permitted by the compressibility of the intervening texture; and in other situations. Again, the movable joints admit of a very varying degree as well as character of motion; but the same textures enter into the composition of all, whether the movement be great or little. Thus, all movable joints are covered with cartilage, and lined by a delicate membrane, which pours out a lubricating fluid called *synovia*, the membrane being thence named *synovial*. Fibrous tissue is arranged in different forms around the exterior of joints, in some instances being spread over them, in others collected into round bundles or flat bands, called ligaments; and these are in two instances, the hip and knee, found in the interior of the joints, holding their surfaces together, so as to check the movements. The form of different joints is naturally associated with their movements, and has given rise to a convenient classification of them into the *ball* and *socket* joints, the *hinge*-joints, and the *flat* joints. The first, of which the only perfect examples are the shoulder and hip, admit of the greatest variety and extent of motion,—a rounded head playing in a hollow or concave socket. The hinge-joint, as the elbow, knee, ancle, fingers, and toes, admits of the bending of the joint at different angles, like a hinge; but many of these allow of other movements to a limited extent. In the flat joints, two plane surfaces are adapted to each other; and, with rare exception, only a limited and gliding movement of one surface on the other is allowed of, as in the yielding of the tarsal or instep bones, for the purpose already noticed. Modification or blending of these special characteristics exists for appropriate purposes; but in all, the mechanism is adapted so as to constitute as perfect a security against the risk of displacement or injury, as is consistent with the requirements and efficiency of the particular joint.

THE MUSCLES.

The active power by which the joints are rendered serviceable resides in the *muscular* tissue. It has been already remarked that it is difficult to limit the usefulness of the muscles. They are found in almost every part of the body; for nearly everywhere their active agency is required, more or less directly, to assist, control, or perfect the functions of different organs, in addition to their more manifest action in moving the limbs. Thus, breathing, the circulation of the blood, and the digestion of the food, cannot be accomplished without muscular action; and the voice and the efficiency of the senses are dependent on it. Each of these subjects will be dealt with in its turn; the present remarks will be limited to the more direct and palpable action of muscles on the trunk and limbs.

The muscles constitute what is usually termed the flesh of the body. Muscular fibre is endowed with the property of contraction. But this contraction is a primary action, occurring when the muscle is at rest, and not consequent on any previous stretching of the tissue, as is the case in an elastic texture. Therefore we speak of muscular action as active contractility, to distinguish it from passive contractility or elasticity. How this contraction is effected is still a question; but it may be remarked that when the primitive fibril, already described (see p. 17), is examined with a high magnifying power, it is found to consist of a single row of minute square-shaped particles, separated by a succession of intervals; and it is supposed that the approach of these particles to each other is the cause of the shortening. However that may be, we know as a fact that contraction consists in the shortening of the length of a muscle, accompanied by increase in its thickness; and further we learn by experiment that this loss in one respect and gain in the other correspond; that there is no actual increase in the bulk of the muscle as a whole. This property of contractility which resides in muscles may be excited in various ways, as by mechanical irritation or by galvanism; but there is no doubt that its natural stimulant is nervous influence, supplied from one of the nervous centres.* The bulk of a muscle is, within certain bounds, increased according to its use: thus, any particular muscles, which are specially employed in some laborious occupation, grow larger; and if any muscles are disused,

* See page 89.



Diagram, showing the arrangement of the muscles of the shoulder, upper arm, and fore arm, and the passage of the extensor tendons of the thumb and fingers beneath the posterior annular ligament of the wrist.

as when a limb is kept at rest on account of a broken bone, they shrink and become small; and this is likewise naturally the case in a paralysed limb, which cannot be used because the supplying nerve-power is withdrawn. Most muscles have attached to them *tendons*, consisting of inelastic fibrous tissue, arranged, according to the requirements of the particular muscle, into rounded bundles, sometimes of great length, or spread out in expanded sheets. The use of tendons is to form a convenient connection between a bulky muscle and the part it is designed to act upon. Thus, all the large muscles, which act on the hand and foot, terminate in these rounded fibrous bands, which occupy but a small space as they pass to their several destinations even to the ends of the fingers and toes.

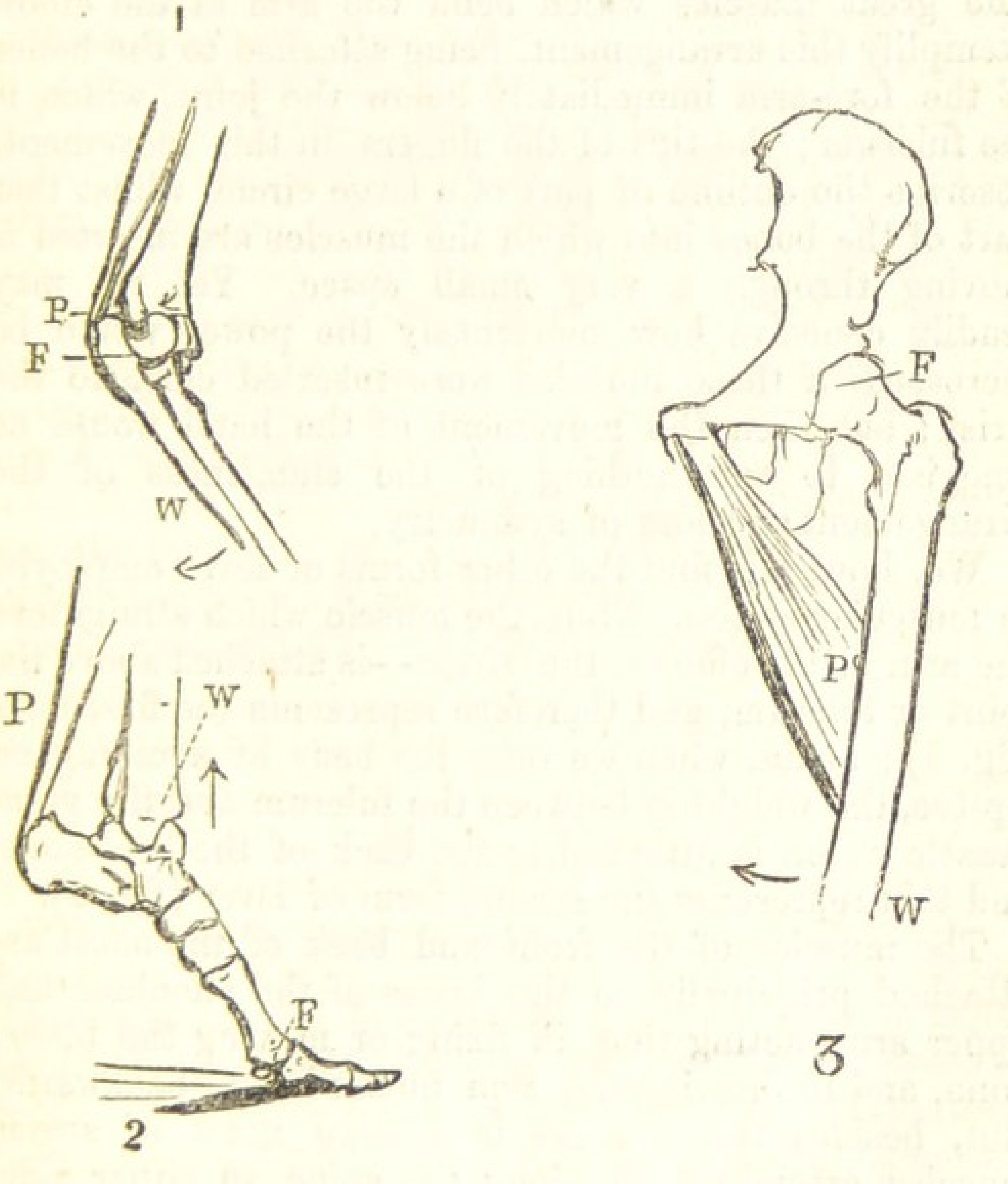
The many uses to which muscles are applied require that they should be of various forms; and such is the case, to an extent that makes it difficult to classify them for popular understanding. Those which belong to the limbs are principally collected into bundles or masses, whilst those which surround different parts of the trunk are chiefly spread out in expanded layers. There is, however, a remarkable set of muscles which envelope and help to form various cavities and tubes; as in the heart and blood-vessels, the stomach and alimentary canal, which, as already remarked, will be noticed in due course.

In order to understand the action of the muscles upon the limbs, it will be requisite to say a few words on the different forms of lever; for, it is scarcely necessary to observe, all the arrangements which exist for securing efficiency of muscular action and economy of power exemplify the perfection of mechanism.

A *lever* in use implies three things: 1. The passive instrument by which the power is applied; 2. The active moving power; 3. A fulcrum or fixed point. In addition to these there is, of course, the weight to be lifted or the resistance to be overcome. Thus, in rowing, the oar is the lever, the rower is the active moving power, the water is the fulcrum, and the boat is the weight to be moved. Now, it will be observed that there is a certain relation, in the example given, of the fulcrum to the moving power and the resistance, viz., that the last is between the two former. But this is not uniformly so; and the variation in the relative position of these parts to each other constitutes the three different forms of lever.

In the *first* form of lever, the fulcrum or point of resistance is between the moving power and the weight. This is the case when we use a crow-bar to lift a heavy stone, and place a block of wood between the stone and the hand, to rest the bar on. The oar in rowing is an example of the *second* form of lever. In the *third* form, the power is applied between the weight to be moved and the fulcrum: thus, if an angler hook a fish, and proceed to land it, he fixes the large extremity of his rod and thus makes it the fulcrum, whilst he raises the opposite end with his hand, thus applying the power between the weight which is represented by the fish and the fulcrum or fixed extremity of his rod.

It is this third form which is much employed in muscular action, because, by the attachment of a muscle close to the fulcrum, great rapidity of movement is acquired, though at the expense of power.



LEVER ACTION OF MUSCLES.

Fig. 1. Elbow-joint, during extension, by action of triceps. 1st Order.
Fig. 2. Ancle-joint, during elevation of body by the agency of the Tendo Achillis upon the Os calcis. 2nd Order.
Fig. 3. Action of Adductor longus on the femur. 3rd Order.

F. Fulcrum. W. Weight. P. Power.
← Indicates the direction of motion.

This becomes apparent if the example just given be considered; for the nearer the rod is held to the larger end, the heavier the weight of the fish appears to be, and in one sense is. But at the same time it is obvious that, whilst that part of the rod which is grasped by the hand is moving over a short space, or the segment of a small circle, the opposite extremity is sweeping over a large space, or describing part of a large circle. The great muscles which bend the arm at the elbow exemplify this arrangement, being attached to the bones of the fore-arm immediately below the joint, which is the fulcrum; the tips of the fingers, in this movement, describe the outline of part of a large circle, whilst that part of the bones into which the muscles are inserted is moving through a very small space. Yet we may readily conceive how enormously the power would be increased, if these muscles were inserted close to the wrist; but then the movement of the hand would be sluggish, to say nothing of the clumsiness of the arrangement and loss of symmetry.

We, however, find the other forms of lever employed in muscular action. Thus, the muscle which straightens the arm at the elbow—the *triceps*—is attached above the joint or fulcrum, and therefore represents the first form (fig. 1); again, when we raise the body by standing on tip-toe, the weight is between the fulcrum and the great muscle which is attached to the back of the heel-bone, and this represents the second form of lever (fig. 2).

The muscles of the front and back of the chest are attached principally to the bones of the shoulder and upper arm, acting thus in fixing or moving the blade-bone, and in drawing the arm forwards and backwards. But, besides these, there is a large mass of strong muscles extending all along the spine on either side, and employed to raise the body when bent, and to maintain the erect posture. Another set of strong muscles in front, and extending down to the basin or pelvis, bends the spine forwards, and assists in various efforts when the breath is held, or in coughing, sneezing, retching, &c. Muscles pass from the front and back of the spine to move the head in different ways. Large and powerful muscles pass from the back and inside of the pelvis to the thigh-bone, to move it in various directions, and to aid in maintaining the body erect on the legs, the weight being thus poised on the heads of the thigh-bones. On the thigh itself, special muscles are appropriated to the movements of the leg, in straightening or *extending* it, and in bending or *flexing* it at the knee-joint, the *patella*, or knee-pan, acting as a pulley over the front of the joint in the former movement. In like manner those muscles which are designed to move the foot and toes spring from the front and back of the leg; and some small ones occupy the sole of the foot. In the upper extremity the muscles correspond to a certain extent with those in the lower; but there are others specially adapted, from their attachments, to roll the radius round the ulna, and thus to turn the palm or back of the hand forwards. The *tendons* are collected under strong ligaments at the front and back of the wrist, where they are bound down before they proceed to be distributed, chiefly to the fingers (see fig. p. 33).

SECTION IV.

THE SKIN AND ITS APPENDAGES.

The skin forms the investment or covering of the exterior of the body, and is complex in its texture, and endowed with important functions besides the mechanical one referred to. The hair and nails are appendages of the skin.

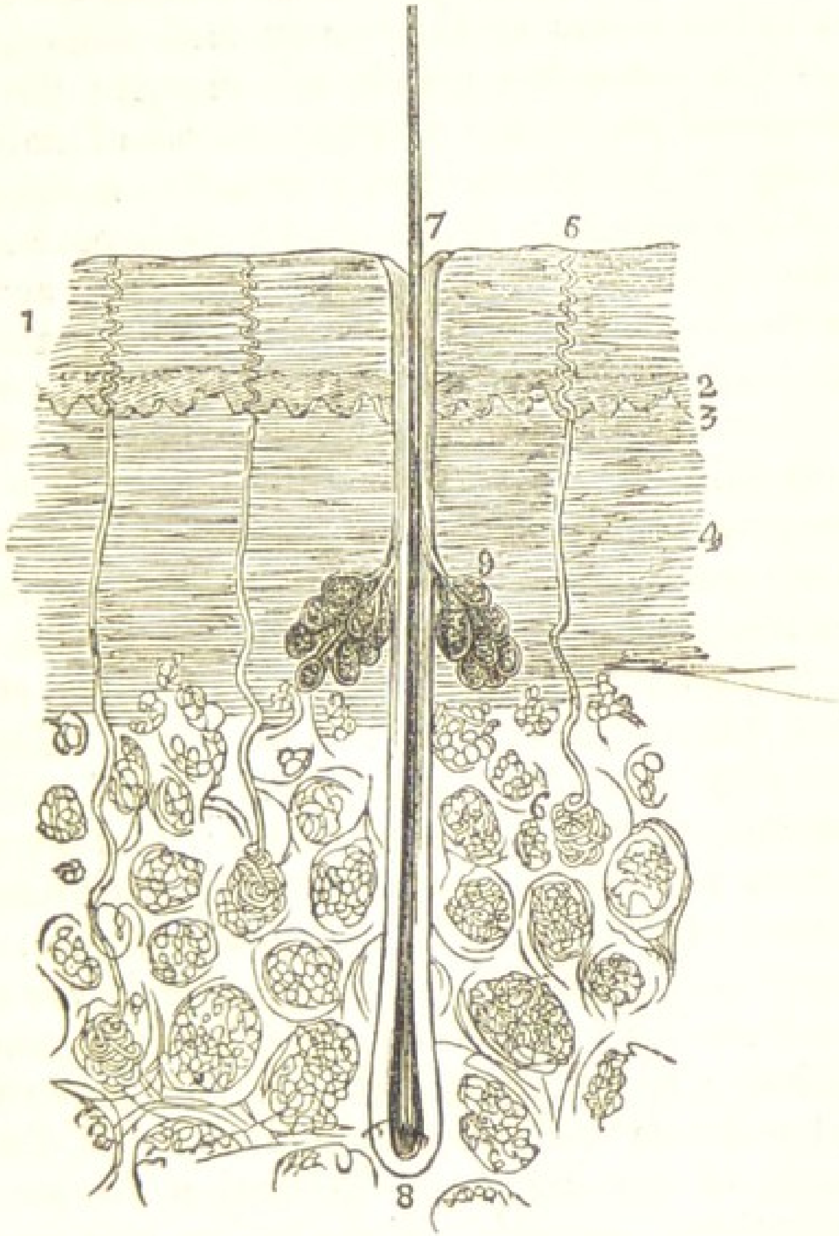
The various uses of the skin which render its structure complicated are, that it is highly sensitive, and capable of distinguishing various sensations, especially at some parts; that it possesses the property of *ex-*

creting or pouring out, as well as of *absorbing* or taking up, material (p. 42).

The true skin or *corium*, therefore, is an organised texture, containing blood vessels and nerves. It is shielded by a protecting covering, which is called the *cuticle* or *epidermis;* and this is produced by the true skin. The proper texture of the corium is fibro-cellular, and it is very elastic and pliable: its surface is woven more closely together than its deeper part; and in the meshes of the latter fat-cells are found. The free mobility of the true skin depends on the presence of loose connective tissue beneath it.

The *cuticle* consists of several layers of flattened *cells* or *scales*, varying in shape; the deeper layers are softer and have in them colouring matter, which is the cause of the difference in the tint of the skin: this portion of the epidermis is called the *Rete mucosum*, and the pigment it contains is most abundant in the Negro. The scales of the cuticle are constantly being cast off, and the loss is replaced by the production of fresh scales from beneath. Friction or pressure increases this growth; and thus the cuticle becomes very thick where the skin is constantly pressed or rubbed, as on the soles of the feet, and in the hands of labouring men. The cuticle not only protects the true skin from injury, but preserves its elasticity by limiting evaporation from its surface. It also modifies the effect produced by the contact of any external object; for, without its cuticular covering, the corium would be much too sensitive to act as an organ of touch or perception, as is learned by painful experience when it is exposed by the action of fire or of a blister. An account of the texture of the skin, and especially its inequalities called papillæ, in relation to the sense of touch (p. 104), will be deferred until that subject is considered in connection with the other senses; but the arrangement by which the skin is kept moist and pliable has still to be noticed.

There are two sets of glands in the skin which pour out a different secretion on its surface.* The *Sudoriparous*, or sweat-glands, which produce the watery secretion, are very abundant, consisting of the simplest



SECTION OF SKIN.

1. Horny layer of cuticle.
2. Rete mucosum.
3. Papillary layer of cutis.
4. Cutis.
5. Deeper areolar (or net-like) portion of cutis, containing fat-cells.
6. Sudoriparous gland.
7. Hair.
8. Root of hair.
9. Sebaceous gland.

form of gland structure, a coiled duct terminating, after a spiral course through the texture of the true skin, in a

* For the definition of a "gland," and the explanation of "secretion," see next section (p. 42).

straight tube on its surface, and between the papillæ (p. 43). The *sebaceous* glands also open by tubular orifices on the surface; they produce an oily matter, which aids importantly in preserving the softness and pliability of the skin. The sweat-glands are most abundant in the palms of the hands and soles of the feet, where the sebaceous glands are absent; the latter are most numerous in the neighbourhood of hair. Retention and accumulation of this secretion is apt to produce irritable pimples on the face and other parts.

The quantity of perspiration varies according to circumstances, being, as regards its watery vapour, about twice as much as that given off by the lungs; and one of its uses is to cool the heated skin by evaporation. A free action no doubt aids materially in cleansing the skin of the superfluous cuticle scales. The perspiration is acid, and contains some salts and other ingredients in small quantity. Carbonic acid is also given off from the skin; and in this respect the surface of the body assists the lungs. There is no doubt that the skin is also capable of taking up, or absorbing, gases, and even water; and the poisonous effects of a metallic preparation, such as arsenic, may be thus produced by rubbing it into the skin.

The constant shedding of the scarfskin (or epithelial) scales from the cutaneous surface, and the generation of fresh scales, are suggestive of their office being allied with the cleanliness and functional activity of the skin, in addition to serving as a protection to its sensitive organisation. Although perspiration acts in removing the superfluous and effete scales, soap and water, and friction, are valuable adjuncts in this process, especially in those whose occupations do not encourage free perspiration. Friction *before* bathing loosens and detaches the epithelial scales, and promotes a healthy glow of the skin; friction *after* bathing restores the equilibrium of the circulation. The sedentary requires ablution more than the hard-working man; and friction is as important as, perhaps more so than, bathing; but they should be combined. With a rough, wet towel they may be employed simultaneously.

The HAIR is said to be an appendage of the skin, because its texture is essentially similar to that of the cuticle. Each hair consists of fibre-like, horny cells, which are closely bound together, but sometimes more loosely packed in the interior; externally it receives a covering of overlapping cuticular scales. When a hair is drawn out from its bed, it is found to be deeply set in the true skin, and into the fat beneath. This bed is called the *hair follicle;* and at its bottom is a small conical projection of the true skin, a *papilla*, from which the hair grows, just as ordinary cuticle is produced from the surface of the cutis. The hair follicle is also lined by cuticle, and spreads into a bulbous enlargement at the bottom; its form and depth may be generally seen when a hair is forcibly drawn out, for the follicle itself is often pulled out with the hair. Thus, this tubular bed or follicle is really a deep depression in the true skin, rather than a perforation of it; for the cuticle is continued into the tube, and lines it to the bottom, forming a sheath to the hair, until the root comes in contact with the papilla from which it grows.

The NAILS are another modification of the common covering of cuticle; but here the scales are very closely compacted, so as to form a very hard and horny substance, especially on the surface. The arrangement for the development and growth of the nail is very similar to that of the hair. Its back edge fits into a semilunar groove in the true skin, and its under concave surface rests upon a corresponding convex surface of the same structure. This bed is marked by a series of ridges and intervening furrows, running from the root to the tip of the nail, which is also grooved to fit into these inequalities. Thus the nail grows chiefly by the addition of fresh cells or scales at its root; but it also receives additions from its bed, as it is pushed forwards from behind; and it is, therefore, thicker and stronger as it approaches the tip of the finger, from which it finally projects, so as to protect this delicate organ of touch.

THE GLANDS.

As the Glands perform an important part in the waste and repair of the frame by excretion and secretion, it will be necessary to describe briefly their structure and function, before proceeding further.

By the word *gland* is meant an organ which separates something from the blood, that is either deleterious to the living body or requisite for its well-being. When this product is deleterious, the act is usually called *excretion*, and the same name is applied to the matter thus got rid of, as in the separation of carbonic acid by the lungs; when the product is useful, as the saliva or gastric juice, it is called a *secretion*. Thus, as all these products are obtained from the blood, it is essential that glands should possess blood-vessels, which they do usually in abundance, and further that they should be provided with some means by which their secretion should be carried to its destination; and this is accomplished by means of open mouths, or of ducts terminating by open mouths or in receptacles; the salivary glands exemplify the former arrangement, the liver with its gall-bladder the latter.

Further, glands necessarily possess a peculiar structure for the purpose of secretion; and this consists, apparently, in the presence of the cells, lining the texture or cavity, as well as the duct from which the product of the gland is derived. How this process is accomplished is not known; still less can we comprehend by what influence or law any particular gland produces its special secretion. No light has been thrown on this subject by the arrangement of the blood-vessels, or the circulation of the blood through the glands. We know that the quantity of a secretion or excretion is proportioned and timed in accordance with the need for it, and also that more blood passes through a gland in active duty. Observation also proves that nervous influence modifies secretion; but this throws no light on the above question, which is, in fact, as much a mystery as the selection of suitable materials for repair after injury—the supply of phosphate of lime, for instance, in the union of a broken bone.

The minute structure of glands presents itself in two different forms; either as (1) a simple short tube, with an open mouth, like the finger of a glove, and this tube may be prolonged and coiled upon itself, but still it terminates by an open mouth upon a surface, such as the skin or mucous membrane; or (2) this tube may divide and subdivide, until finally it terminates in a number of little sacs or vesicles, arranged in clusters like currants on a stalk, and attached to the subdivisions of the duct which receives their secretion. Exemplifications of these different forms of gland will be given in the succeeding sections; but it may be now pointed out that each of these varieties possesses one characteristic, which is common to all secreting organs, including the lungs,—that of presenting a large extent of surface over which the terminations of the blood vessels ramify, so as to afford the material necessary for secretion.

SECTION V.

ORGANS OF DIGESTION.

We are ever moving onward; one generation follows another. Maturity succeeds growth, and in turn gives way to decay; the ever-recurring waste is supplied by new material from without, till at last the power of repair fails, and the fabric falls to pieces. It is this never-ceasing waste, combined with loss of heat, which food is designed to supply; and whenever, by reason of any disturbing cause, aliment cannot be taken, or if taken, cannot be digested or assimilated, death takes place prematurely, as in the consequence of any severe shock or injury, or from disease; though, of course, dissolution may occur more rapidly in other ways.

In animals the arrangements which exist for converting the aliment into blood are more or less complicated, according to the requirements of each class; and this conversion is called *assimilation*, a comprehensive word which includes *digestion*, or the solution of the food in the stomach prior to its being further prepared and fitted for constituting a part of the living fabric.

Vegetable life is sustained and growth is provided for on the same conditions as govern these requirements in animals; but the process of assimilation commences with vegetables at a later stage than with animals, because their aliment is conveyed to them in a fluid form, and does not need all the arrangements which are necessary before this stage is reached, especially in the higher forms of animal life. It is true that in the lower forms the process of *alimentation*, or the supply of nutriment, is very nearly allied to that of vegetables; but then their structure and their organs of assimilation are comparatively simple. In like manner it may be remarked that the conversion of vegetable food into flesh is a more complex proceeding than the assimilation of flesh; therefore, as we should expect, vegetable feeders have more complicated digesting organs than those which feed on flesh; and, in this sense, the former class may be regarded as preparing their food for the latter—the vegetable feeders assimilating herbage, and being themselves used as food by the feeders on flesh. Apart from the knowledge acquired by experience, the construction of man's assimilating organs shows that he is designed to live on a mixture of animal and vegetable food.

In the succeeding description it must be borne in mind that food is required for two purposes, the supply of solid waste and the production of heat; the latter is not less essential than the former.

Now, the sources of waste are more numerous than those of supply. In fact, the alimentary canal is charged almost exclusively with the latter function, though not entirely so, for the lungs are continually renewing the lost oxygen, which passes off in the form of carbonic acid; and the skin, as just now remarked, may occasionally help by absorption. This oxygen is, however, so to speak, the supporter of combustion, whilst the food which is assimilated supplies the material for combustion. In considering the subject of *food*, we have, therefore, to notice those forms which are subservient to each of these important purposes.

As the bulk of the body consists of so large a proportion of water, so the solid food taken also contains a large quantity, but not sufficient to supply the waste from so many sources without the addition of drink.

Every act, even of the simplest kind, implies an expenditure of nervous energy or physical force, which must be recruited.

External circumstances necessarily determine in great measure the quantity and quality of the aliment; but the two which are the most influential are the activity of the individual, and the temperature in which he lives. This activity may be either mental or physical; for the former, by taxing the great nerve centre, produces exhaustion as sensibly as physical exertion. Again, where the external temperature is high, those elements which are necessary for the generation of heat are required sparingly. These and other observed facts have given rise to a division of food into those kinds which supply each form of loss.

When resolved into their elements, it is found that heat-producing food contains chiefly carbon and hydrogen, and also oxygen; whilst nitrogen is an essential constituent of those articles of diet which supply nourishment to the different tissues, with the exception of oleaginous or fatty matters, which do not contain this element (see *ante*, p. 15). It must not, however, be supposed that these two classes of food are exclusively employed for these several purposes, for a piece of flesh or muscle contains all the elements necessary for both nutrition and heat; and the same may be said, in a qualified sense, of fat, which contains no nitrogen. The conditions, therefore, necessary for food to be capable of sustaining life are, that the requisite elements should be present, and this may be the case in a purely animal or a purely vegetable diet; for in the latter there exist albumen and compounds that contain the same elementary constituents, as fibrin and casein, which, it has been shown (*ante, p.* 15), compose the primary tissues of the body.

But, as the supply is to be commensurate not only with the quantity but with the quality of the loss, the question of diet turns upon the proportion of the ingredients contained in each form of food, for some articles of diet contain an excess of one ingredient and an insufficiency of another; and this renders it necessary that man's diet should be such a mixture as to consist, as nearly as may be, of such articles as contain, in conjunction, the requisite quantity of each essential ingredient. Thus, the exclusive use of either meat or bread, which represent severally animal and vegetable diet, would involve the necessity of an excess in quantity of either, in order to obtain the required amount of two elements which are being constantly lost by waste, viz., nitrogen and carbon.

It is not, however, simple textural waste which has to be supplied by albuminous and fatty substances, but also the continually recurring exhaustion of force resulting from vital activity. In the renewal of this force the starchy and saccharine matters play an important part; therefore an excess of the albuminous material in the form of meat is not only superfluous and wasteful, but positively injurious, as such excess must be somehow disposed of to restore the balance. Animal food is generally used in excess where it can be obtained;

whilst vegetable food, with its rich supply of nutritive and force-giving materials, is comparatively neglected.

Various diet tables have been constructed in accordance with the knowledge thus acquired, which agree essentially with what is found practically to constitute a wholesome and sufficient diet; but of course no rules as regards food can be applied universally, but must be modified according to many circumstances of natural temperament, health, and habits, as well as by the atmospheric temperature and the exercise taken. For a healthy man, actively engaged, the following proportions of the *simplest* form of diet will give a fair average of the necessary ingredients for supplying the daily waste of solid material and of heat. Cooked meat, about half-a-pound; bread, about one pound and a-quarter; butter, or fat, about a quarter of a pound; water, about three pints or rather more, calculating sixteen ounces to the pound or pint.

We may here pause for a moment to remind the reader of the practical lessons to be acquired from these simple facts: lessons based alike on scientific investigation and experience. A mixed diet in moderation is that which is best calculated to promote health. Excess is prejudicial in many ways: by overtaxing the digestive power, by supplying some element in redundance, or by over-loading the blood-vessels, and thus compelling the excretory organs to perform unnecessary work to get rid of that which is not needed; and this is a rife source of derangement in some one organ, which leads to a loss of equilibrium and general disturbance of functional duty, ending, if perpetuated, in organic disease. Habitual excess in eating, as certainly though more insidiously, curtails life, as excess in the use of alcoholic drinks.

Further, we learn how heat is generated from food, It may be elicited temporarily by exciting the circulation to more activity by alcohol; but stimulants are only a limited source of heat, and unnecessary in its production. The inhabitants of northern climates consume largely the heat-producing oleaginous compounds; but in the tropics animal food is sparingly consumed, and grain-food—such as rice in India—is a staple article of native diet.

As solid food requires to be broken up or ground before it is passed into the stomach for digestion, the mouth is provided with the necessary mechanism for this purpose; and this consists of the teeth, which are firmly planted in the jaws, and muscles to move the lower jaw upon the upper.

The TEETH.—The character and form of the *teeth* is so intimately associated with the habits of animals that it is sufficient for any one versed in the subject to see the former in order to judge of the latter. Thus, the teeth of a predaceous animal, which feeds on other animals, are specially calculated to help it to seize its prey; whereas the grinding teeth are scarcely needed, as the flesh is only crushed slightly before it is swallowed. But in the herb and grass feeders, large and chisel-like front teeth are required to crop their food, and strong and rough back teeth are required for grinding it. The contrast between the mouths of these two classes is therefore very striking. In man, as we should expect, we have an intermediate development between the two.

The teeth may be regarded as appendages of the jaws, and are planted in deep sockets from which they spring. They are organised, *i.e.*, they possess vessels and nerves; they have a definite structure, and are subject to the various changes of growth, maturity, disease, and decay.

Man is supplied with two sets of teeth; the first set adapted to the small jaws of childhood; the second set, more numerous and of larger size, which replace the former, and are designed to last for the remainder of his life. The rudiments of both these sets are found in the jaws before birth.

As the *permanent* teeth grow they press upon the fangs of the first set, which become absorbed, and ultimately the latter fall out to make way for the new set.

The moving power, by which this grinding mill is set in motion, consists of four pairs of muscles, all which are attached to the lower or moveable jaw.

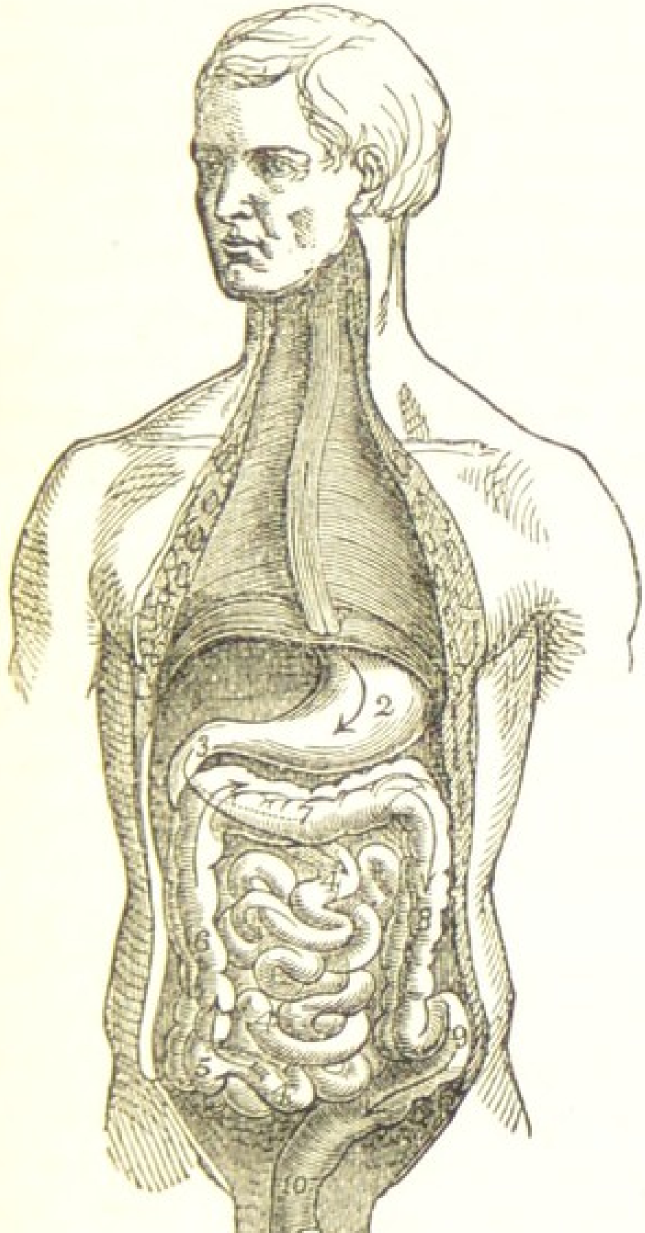
During the grinding or *mastication* of the food, it is moistened and softened by mixture with the saliva, which also acts chemically on it, as will be explained after the description of the act of swallowing. When a mass of food is thus prepared, it rests in the centre of the mouth on the tongue. It will be necessary to leave it here for a short time, whilst attention is directed to the very interesting and somewhat complicated arrangement which exists for completing the swallowing of the food with security.

On looking into the back of the mouth with the aid of a mirror, a sort of curtain will be noticed stretching from side to side, where it is attached, by a forked division, in front of and behind the *tonsil* gland; in the centre a pointed body, the *uvula*, hangs down. The side folds contain muscles, whose office it is to prevent the food, when carried back, from returning into the mouth, or from passing up into the nostrils; and this is accomplished by these muscles drawing up the curtain or *soft palate.* But here a more serious risk is incurred; for the mass has to pass over the upper orifice of the air-tube, or *larynx*, which lies in front of the food-tube or *pharynx.* The introduction of the smallest particle of either food or drink creates at once a choking sensation, and violent coughing to expel it; for the orifice of the air-tube is extremely sensitive, in order to raise the alarm and guard it against this risk.

Protection is afforded by a double provision; the orifice itself can be closed by muscles (see description of "Voice" further on), and also by a trap-door being attached to the back of the tongue, called the *epiglottis*, which fits over the entrance to the larynx. Therefore, when the mass of food is thrust back by the action of the tongue, the epiglottis at the same time is fitted over the top of the air-tube, which is simultaneously raised to meet it; as may be felt by placing a finger on the front of the windpipe during swallowing. In this way food or drink passes safely over the air-tube into the *upper* part of the food-tube or pharynx. The remainder of this act, by which food is carried onwards through the *lower* part of the food-tube, which now receives the name of *œsophagus,* to the stomach, is effected entirely by involuntary muscular action. In fact, the earlier part of this act is far more independent of the will than would be supposed; as may be proved by attempting to swallow the saliva several times in succession: this cannot be done unless there be saliva or something else to swallow; the presence of something at the back of the mouth excites the act, which cannot then be resisted. In this way the food is passed on to the stomach, where digestion commences. The swallowing of fluid is effected in precisely the same way.

The *salivary glands* are arranged in three pairs, and they pour their secretion by ducts into the mouth. There are also many other small glands, of the same character, scattered over the mucous membrane of the cheeks, lips, and tongue. The saliva, when fresh, is slightly alkaline, and contains little more than five per cent of solid matter, the rest being water. The secretion is more or less constant, but is greatly augmented by the movements of the jaws and by the taste of food. Its chemical action is to convert the insoluble starch, which is so abundant in vegetable food, into soluble grape sugar. It has been calculated that the salivary glands produce about two or three pints in the twenty-four hours; but this must, of course, vary according to circumstances. There is no doubt that the saliva helps the sense of taste, by moistening the mouth and dissolving some of the constituents of food; partial suspension of this useful secretion assists in causing the dryness of mouth, loss of taste, and thirst in fever.

We have thus seen how much this early stage of preparing the food for nourishment is dependent on muscular action; and we shall find that the succeeding steps also require mechanical assistance to supplement the chemical action of solution. The stomach and intestines are, therefore, essentially muscular organs as well as organs of secretion.



Alimentary Canal (*in situ*).

1. Œsophagus.
2. Stomach.
3. Duodenum.
4. Small intestine.
5. Cœcum.
6, 7, 8. Colon.
9. Sigmoid flexure.
10. Rectum.

The form of the *stomach* is seen in the accompanying illustration. It is a large, sacculated cavity, capable of great distension; stretching across the upper part of the abdomen, and chiefly under the lower part of the left ribs. Its left, or *cardiac*, extremity is large, where the œsophagus terminates; its right extremity — the *pylorus*—is smaller, and guarded by a thick ring of muscular fibres and a valve of mucous membrane, so as to prevent the food during digestion from passing too soon into the intestine. The stomach has a large supply of blood vessels, and derives its nerves from two sources.

The mucous membrane is covered with cylindrical epithelial cells, and studded all over with the minute orifices of numberless tubular glands, some of which are branched at their extremities (p. 43); it is from these that the *gastric juice*, or dissolving fluid of the stomach, is poured out at the period of digestion; and in such quantity that it has been calculated to amount, according to circumstances, to ten or fifteen pints or even more during twenty-four hours. But the active ingredients in this fluid are, as in the saliva, a very small percentage of the whole, between five or six in one hundred, the remaining ninety-four parts being water. It is clear, without odour, and with very little taste. It is acid, from the presence of hydrochloric acid; but the most important and abundant constituent is called *pepsin*, in which, combined with the acid, the solvent property of the gastric juice especially resides.

The muscular action of the stomach aids this process importantly, by keeping its contents constantly moving to and fro, and thus bringing each part successively into relation with the solvent fluid; just as we should stir about anything which we wish to dissolve. In this way the food is converted into what is called *chyme*, and is then permitted to pass the pylorus into the intestine.

We may here again pause, for a moment, to consider how much control we have over the earlier stages of digestion, and how imprudent it is to neglect the exercise of that control, in so far as it is conducive to health. The slow and careful mastication of solid food is essential, not only to prepare it mechanically for solution in the gastric juice, but also to secure a proper admixture of a sufficient quantity of saliva with it. For this reason it is a mischievous habit to sip any fluid repeatedly whilst eating, as the secretion of the saliva is thereby suppressed: it is far better to quench thirst with a draught of *water*, before commencing a meal; this is soon absorbed, after it is drunk.

Although variety of food is desirable, yet indulgence in this respect often induces excess, by the appetite being tempted beyond the capacity of the stomach to digest its contents, or the requirements of the system. Stimulants with a meal may aid a feeble digestion by exciting the activity of the stomach; but they are certainly superfluous, and often prejudicial, when the digestive power is healthy. A protracted meal is, therefore, better digested than one swallowed hastily; and meals taken at sufficient intervals—say four or five hours—are more wholesome than the same quantity of food taken at short intervals, whereby the stomach is kept continuously at work, and digested and undigested food are mixed together. In sickness, of course, circumstances may change the conditions, and require different treatment.

CHYME, then, is the pulpy or semi-fluid product of digestion in the gastric juice, consisting chiefly of the albuminous compounds, mixed with the fatty parts of the food but little changed, and also with the starch in part rendered soluble by the action of the saliva converting it into sugar; added to these is the non-nutritious or indigestible portion of the food, which is permitted also to pass the muscular ring that guards the pylorus, when the nutriment is extracted from it. Probably a large proportion of the fluid which is swallowed as such, together with the water extracted from the solid food, is absorbed by the vessels of the stomach; though, no doubt, this action is continued subsequently in the intestines.

Before proceeding with the further changes which take place in this long canal, it will be necessary to describe its structure, as well as that of the liver and pancreas, which pour their secretion into the alimentary tube immediately below the stomach; and also that of the spleen.

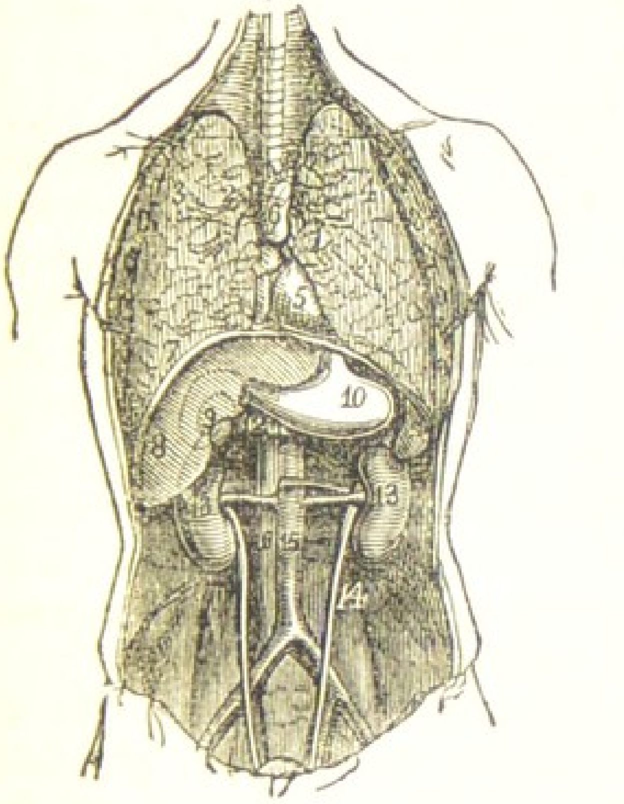
The entire length of the *intestinal canal* in a full-grown person is about twenty-five feet; of which four-fifths is of small calibre, and is called *small intestine*, and one-fifth is *large intestine*. The longer and smaller part of the canal floats loosely, except at its commencement and termination; and there is a remarkable valve, formed by a reduplication of the mucous or lining membrane of the bowel, which guards the communication between the small and large intestine, and is usually an effective protection against any return of the contents of the latter, when distended, into the former.

In addition to the numerous glands scattered along this canal, there are, on the surface of the mucous membrane of the small intestine, a number of minute projections, which are so closely arranged, and so largely supplied with blood-vessels, as to give it a velvety appearance; these are named *villi:* their office is to take up or absorb the digested food; *i.e.*, the chyle; and for this purpose a minute tube, called a *lacteal* vessel, occupies the centre of each *villus.*

The Liver is the largest gland in the body, and has a very important office to perform—viz., the production of the bile. Its position is under cover of the ribs on the right side, and stretching across the centre a little into the left side, where it comes into relation with the stomach: its surface is rendered smooth by its covering of serous membrane; and the form of its upper part is moulded to the arch of the great muscular partition between the chest and abdomen, called the *diaphragm*, to be described by-and-by (pp. 66 and 77).

The liver is supplied largely with blood, for the separation of the bile; and this blood is chiefly derived from the great veins which collect it from the spleen and alimentary canal, and terminate in one large vessel called the *portal vein.* But besides this the liver is nourished by an *artery* named the *hepatic;* and other *veins*, likewise called *hepatic*, return the blood to the general system, after the bile is separated; and a special duct is provided to collect the bile and carry it to its destination. Thus, in the economy which is witnessed in the functions of many organs, the liver has to purify the blood of noxious ingredients, which are utilised in the digestion of the food.

As the secretion of bile is constantly going on, though more actively during digestion, a reservoir is provided for it, when it is not needed, in the *gall-bladder ;* and the duct from the liver meets that from the gall-bladder, to form one common duct, which empties itself into the small intestine ; through this communication the superfluous bile finds its way into the reservoir, where it is stored until its presence in the intestine is solicited by the process of digestion.



THORACIC AND ABDOMINAL ORGANS (*in situ.*)

1. Trachea.
2. Bronchus (right).
3. 4. Lungs.
5. Heart, overlapped by lungs.
6. Aorta.
7. Diaphragm.
8. Liver.
9. Gall-bladder.
10. Stomach.
11. Spleen.
12. Pancreas.
13. Kidneys.
14. Ureters.
15. Abdominal aorta.
16. Vena cava inferior.

The PANCREAS is another organ concerned in digestion. It is of an oblong shape, and lies obliquely across the spine, beneath the liver and stomach. In structure it is closely allied to the salivary glands, and the fluid it secretes is very similar to that produced by these glands. Its function appears to be chiefly that of converting fat into a soluble emulsion, or milky fluid, and starch into grape sugar, thus assisting importantly the allied glands in digestion ; and probably also aiding the stomach in the solution of albumen.

The delicate duct of this gland emerges at its right extremity, and opens, in common with or close to the great duct from the liver, into the duodenum.

The part which the SPLEEN takes in digestion is, at most, indirect and subordinate. This body is of irregular form, a dark purple hue, and about the size of a small doubled fist. It lies deeply under cover of the left ribs, in close relation with the great end of the stomach. The texture of the spleen is spongy, and its blood-vessels are very large.

The entire absence of any duct has made the function of this organ a subject of constant speculation. Recent observation and experiment point to the conclusion that it is importantly concerned in the preparation of the materials required in the conversion of food into blood, and especially of fresh corpuscles about to be introduced into the circulation.

We are now prepared, after this digression, to resume the consideration of the changes which await the *chyme*, or partly digested food, after it leaves the stomach and enters the duodenum (p. 53).

It was remarked that this pulpy mixture includes the partially dissolved albuminous matter, and the fatty matter mechanically prepared for solution, but not yet changed in other respects; whilst the starch is already partly converted into sugar by the saliva. With these, of course, the secretion of the stomach itself, and the unabsorbed liquid which has been taken with the food, are mixed. Thus it will be seen that it is the business of the glands which are found on the surface of the small intestine, as well as of those which pour their secretion into it, viz., the liver and pancreas, to complete this process, and to prepare the nutrient material for admixture with the blood. In this way the solution of the albuminous compounds is concluded; the fatty matter is rendered soluble by admixture with the bile and other secretions, but probably the bile is the chief agent in converting it into a soluble emulsion; and the starch is further acted on by the secretion of the pancreas, which completes the work of converting it into sugar, commenced by the allied salivary secretion.

It is thus the greater part of the nutriment is prepared for absorption by the blood-vessels, and by the lacteals which are found, as already described, in the villi of the small intestine. The function of the large intestine is to supplement that of the small, in digesting what may be left undigested by the latter, and in further absorbing what has not already been taken up at an earlier stage; the *peristaltic* or worm-like contraction of the canal propelling its contents onwards, and thus bringing them into contact with its surface at various parts in succession.

It is supposed that it is the fatty matter which it is the special duty of the lacteals to absorb; much of the other material, with the fluid swallowed and secreted, is taken up directly into the circulation by the blood-vessels. How this is accomplished will be considered in the next section (p. 59).

The sensations of *Hunger* and *Thirst*, which are designed for an obvious purpose, are more easily defined than explained. Hunger is referred specially to the region of the stomach, and thirst to the mouth, palate, and throat; but each is rather a general than a local sensation, though the nerves of the parts named, but especially of the stomach, would seem to have assigned to them the office of communicating to the brain the feelings which prompt us to eat and drink, and when to desist.

The direct cause of thirst admits of an explanation more readily than that of hunger. A large quantity of water is required to dissolve the different secretions and for various other purposes. This supply is stored in the blood, and a deficiency in quantity at once interferes with the proper performance of many important functions; for the soluble salts and other ingredients in nutrition are not sufficiently diluted. Thus, loss of blood to any extent drains the blood-vessels and produces distressing thirst; and an excess of common salt in the diet calls for more water to dilute it, and thus likewise produces thirst; for the water is positively diminished in the former instance, and relatively so in the latter. An excess of solid food, or a very dry diet, acts in a similar way; so also does copious perspiration; and thirst is the accompaniment of diseases which are characterised by excessive drainage of water from the blood.

Deficiency of nutritious food also disturbs the equilibrium between the material for combustion and the agency by which combustion or oxidation is sustained, and the tissues are starved by no fresh material being introduced into the blood-vessels to supply the waste; yet the craving for food as well as drink is allayed before the supply can reach the vascular system—a circumstance which confirms the supposition that the nerves of the stomach in particular are, so to speak, the nerves of the special senses of hunger and thirst. The craving for drink in fever and some other allied complaints, would seem to be due to an imperfection in the assimilative functions, giving rise to a perverted condition of the secreting organs, which entails effects similar to those just noticed; this is partially relieved by moistening the mouth and palate when they are parched and dry. The lack of appetite under similar circumstances is referable to the same cause, and to a morbid state of the mucous membrane of the stomach, which renders it incompetent to digest food if taken.

Hunger can be borne much longer and with less suffering than thirst, for the body can, for a time, feed on itself, *i.e.*, sustain the solid waste by loss of bulk; but there is a very limited internal resource for the supply of water, and therefore its deficiency is more urgent and more distressing for the reasons already assigned.

SECTION VI.

LYMPHATICS, &c.

In considering the way in which the new material, derived from digestion of the food, is taken up and mixed with the blood, it is necessary to anticipate the next section by remarking that all the blood-vessels, both arteries and veins, terminate in minute ramifications, and communicate with each other through an intermediate set of vessels of uniform size, called, from their slender hair-like appearance, *capillaries*. But, in addition to these vessels, there is another set which pervade the whole frame, and have nothing to do with the circulation of the blood, beyond pouring their contents into the blood-vessels. These are named *lymphatic* vessels, and the fluid they convey is called lymph. Moreover, one division of this system of vessels has the special duty of conveying the chyle from the alimentary canal to the veins; and these have been already noticed under the name of *lacteals*.

The lymphatics commence in various textures, without communication (except at the termination of the great trunks) with the blood-vessels; but at intervals, throughout their course, they pass through little bodies which are called *lymphatic glands*. These appear to consist chiefly of a network made up of blood and lymph vessels, held together by connective tissue, with interspaces occupied by fluid and the all-pervading cells.

The lymphatics contain a nearly colourless fluid, with a slightly saline flavour. This is derived from the various tissues in which the lymphatics originate, and appears to be that constituent part of the waste material which is selected as still available for nutrition. It moves onwards in one direction towards the great vessel, called the *thoracic duct*. The *lacteals* are identical in structure with the lymphatics; differing only in this respect, that they commence, as described, on the mucous surface of the intestine; and, after passing through the lymph-glands found in the neighbourhood of the intestine, terminate likewise in the thoracic duct. The fluid they convey is richer in consistence than the lymph, being of an opaque, milky colour after digestion, and containing corpuscles.

Thus, we see that a provision is made by which digested food shall find its way from the alimentary canal into the vessels which circulate the blood; and also that the fluid, derived from the blood and no longer needed in the nutrition of various tissues, shall be economised and again introduced into the circulation. Indeed the great dilution of many of the secretions requires, as already remarked, a large store of water, and the blood-vessels are the reservoir in which it is kept for use as it is required. Some of this water is necessarily lost, as by perspiration and in breathing, and needs to be replaced from without; but a large quantity is used for the solution of active agents, as in the saliva and the gastric juice in digestion, and is afterwards filtered back into the blood, until again required for some other purpose; there is no unnecessary waste in the animal economy. The part which the lymphatic glands perform is not understood; but there can be no doubt that they effect some necessary change in the lymph and chyle as they pass through them.

The *thoracic duct*—so called from its traversing the thorax—commences in an expanded receptacle below the diaphragm, where it receives all the lacteals, and the lymphatics from the lower part of the body. After proceeding through the chest, at the side of the spine and towards the neck, it terminates in the junction of the two great veins of the arm and head, on the left side of the neck; the lymphatics of the right side of the upper part of the body open into the corresponding vein of that side. These openings are protected by valves, which prevent the blood from flowing into the lymphatics. Indeed, both lacteals and lymphatics are freely provided with valves throughout their course, similar to those in the veins,* to prevent their contents from taking a retrograde direction when subjected to pressure.

The relative simplicity of this nourishing process in the vegetable kingdom leaves but little to be cast off in the form of excretion; and that is accomplished during the active life of the plant by the leaves. In man and the higher forms of animal life, the indigestible or undigested portion of the food is separated and cast off; but besides that several organs are employed in this essential function. The use of the skin in this respect has been already noticed (p. 40); the liver also assists in the way just described (p. 54); the lungs, which are essentially excreting glands, eliminate carbon, of which an account will be given under the head of "Respiration" (p. 78). There is another pair of glands, namely, the kidneys, which take part in this office of excretion, and of which it is, therefore, desirable here to give a description.

THE KIDNEYS.

The form of the *kidneys* in man is similar to that in the sheep, but they are somewhat larger. They are placed, one on each side of the spine, deeply in the loin or lumbar region. In structure the kidney belongs to the class of glands already described as tubular (see page 42); a tube, about the size of a goose-quill, conducts the excretion to the receptacle destined for it within the pelvis.

Each kidney is supplied by a large artery coming from the main trunk, the aorta; and returns its blood, after it is purified, by a corresponding vein to the large vein passing upwards towards the heart, viz., the vena cava.

This excretion consists of many salts in small proportions, but chiefly of a compound called *urea*, which

* See page 68.

is highly poisonous if not removed from the blood. Its principal ingredient, nitrogen, is derived from the waste of the tissues and from the excess of animal food. Its quantity, therefore, is influenced by causes operating on these sources of supply; and so long as the kidney acts healthily and is not overtaxed, it is an important safeguard against the accumulation of unrequired material in the system.

Thus, we find that provision is made to preserve that equilibrium which we term health, not only by the excretion of noxious elements which are naturally produced in the body, in the necessary changes which accompany waste and repair, but also in affording security against the evil consequences of excess. Yet, it should be understood that the former is the natural office of these excretory organs, and that a frequent recurrence of an extra demand on their activity is likely to be resented sooner or later.

In simple language, excess in eating and drinking excites the excretory organs, especially the skin, the liver, and the kidneys, to unnatural efforts; and the consequence is, first of all, functional derangement, and afterwards structural change. There can be no doubt that this is the history of organic disease in a multitude of instances; as surely so as over-stimulation of the heart's action is productive of a similar result. The moral which is taught by these facts is expressed by the single word "moderation."

THE MAMMARY GLANDS.

The only remaining gland, associated with early nutrition and requiring special description, is the *Mammary* gland or breast.

The structure of this pair of glands is follicular; *i.e.*, similar to that of the salivary glands, consisting of many lobules bound together in lobes (p. 43). The chief ducts, into which the smaller ones empty themselves, are fifteen or twenty in number, and are dilated considerably just previous to their termination in the nipple. The mammary gland is very vascular, and covered by a cushion of fat.

Human milk contains rather more than ten per cent. of solid matter, the remainder being water; the solid part consists of casein, butter, and sugar, the last in greatest abundance. In cows' milk the solid matter is more abundant, of which casein constitutes nearly a moiety. There is a very small quantity of saline matter in each.

The milk of the ass most closely resembles human milk.

SECTION VII.

THE BLOOD AND ITS CIRCULATION.

The blood is the life of the body, in that it is the source from which its supply of nutriment is drawn, whereby waste is repaired, and material for growth is provided. The arrangement by which this nutriment is distributed necessarily pervades the entire frame; but the mechanism is simple and readily intelligible, when the structure of the organs concerned in the circulation is understood. The principle, in fact, is that of a force-pump, represented by the muscular heart, by which the blood is driven, with successive strokes, through a series of elastic tubes. Having performed its various offices, this fluid is returned by another set of tubes, and in a deteriorated condition, to the heart; whence it is again expelled by a different channel, that it may pass through the lungs for purification; and being returned once more to the heart, it is prepared again to take its course, as purified blood, throughout every part of the body.

This brief description, therefore, implies—1. The existence of a central muscular organ, divided necessarily into compartments, two of which receive the blood, *i.e.*, the impure blood from the body generally, and that which is returned, purified, from the lungs; and two propel the blood, respectively, through the lungs, and throughout the body. Thus the heart consists of four compartments or cavities. 2. The presence of four sets of tubes or conduits, viz., to and from all parts of the body generally, and to and from the lungs specially. The connection between the extremities or terminations of these conduits is by minute hair-like tubes, thence called capillaries. We have, therefore, to consider, successively, the nature of the blood, which fits it to nourish the body, and the structure of the heart and blood-vessels, by which they are enabled to accomplish the offices ascribed to them. The provisions for purifying the blood will be considered afterwards under the head of "Respiration" (p. 80).

The Blood is a viscid fluid, of red colour varying in intensity, and consisting of seventy-nine parts, in one hundred, of water, the other twenty-one parts being solid matter. It is slightly alkaline, and emits a faint odour when fresh. It is difficult to estimate the quantity of blood in the body; but the result of many experiments serves to point to one-tenth, or rather more, of the entire weight of the body as an approximation to the average amount; so that a person weighing ten or twelve stones would have from fifteen to eighteen pints of blood. The temperature of the blood is about 100° Fahrenheit, but a little higher on the left side of the heart than on the right. As the blood is employed not only to impart nutriment to the frame, but also to distribute oxygen, it contains both solid matter and gas; and it, moreover, receives the refuse matter, which results from the molecular death of the tissues that is constantly going on. It is also, in part, the seat of those changes by which heat is developed.

The colour of the blood differs in the two sides of the heart; on the right side, *i.e.*, in the blood collected from the veins, it is of a deep crimson hue, owing to the presence of carbonic acid gas; on the left side, and in the arteries, it is of a bright scarlet colour, which is due to the presence of more oxygen, which has replaced carbonic acid, got rid of in breathing. The former is called *venous* blood, the latter *arterial*.

If fluid blood be examined under a microscope, it will be observed to consist of a colourless liquid called *plasma*, and of numerous *globules*, or more properly discs or cells, chiefly of a red colour, but some colourless, floating in it. The red corpuscles or cells appear to have a transparent wall, which contains within it the coloured matter or *cruor*. Their size varies between $\frac{1}{3000}$ and $\frac{1}{4000}$ of an inch in diameter, so that it would require ten millions of them to cover a surface an inch square. Usually they are thicker at their edges and hollowed in the centre; but sometimes they absorb fluid, and thus swell. The white corpuscles are comparatively few, larger and more spherical, and variable in form. The plasma, or liquid in which these corpuscles float, is serum, containing fibrin in solution. The shape and size of the corpuscles varies in different animals. If the web of a frog's foot be placed in the field of a microscope, these constituents of the blood may be distinctly seen in circulation.

But if blood be drawn into a vessel and allowed to stand, it undergoes a change called *coagulation*, or clotting, the fibrin enclosing the red corpuscles, and gradually expelling the serum, which floats on the surface of and around the clot. This act of coagulation is resisted as long as the blood is in living circulation.

The blood contains some salts, but its principal solid ingredient is albumen; the salts are chiefly those of soda and potash. There are also present, besides other matters, some oxide and phosphate of iron.

It is supposed that the white or colourless corpuscles are the chyle or lymph corpuscles, and that from them the red corpuscles are formed. Whether these perfect corpuscles undergo any process of disintegration or decay in the vessels, after they have fulfilled the design of their existence, is not known. The fibrin and albumen are employed for nutrient purposes; probably the red corpuscles absorb oxygen in the lungs, and distribute it thus through the body.

Both lymph and blood corpuscles, especially the white, have been seen to exhibit spontaneous movements in tissues, dependent apparently on the protrusion and retraction of parts of their substance like arms. This property characterises their vitality, and has been named "*amœboid*," from Amœba, signifying a low form of animal life, in which similar movements are observed.

THE HEART.

It has been stated that the *Heart* consists of four muscular cavities, which receive and distribute the blood. The receiving cavities have comparatively thin and weak walls, and are called *auricles*, from having ear-like appendages attached to them; the propelling cavities, or *ventricles*, are strong and thick. These four cavities are united into one pyramidal mass, consisting almost entirely of muscular fibre, similar in structure to the voluntary muscles; the apex of this mass is formed by the ventricles, and its base by the auricles; the former being loose and corresponding to the interval between the fifth and sixth ribs of the left side, and the latter or base being attached to the chest by the great vessels which pass into and out of the heart. Its position, therefore, is oblique, being nearly central above, and inclining forwards and to the left side below. A strong fibrous membrane, the *pericardium*, lined by serous membrane, surrounds the heart, and is firmly attached below to the great muscular partition between the chest and abdomen, called the *diaphragm*.

There is considerable difference in the muscular power of the two ventricles; the left has much more work to do in pumping the blood through the system generally, therefore it is twice as strong as the right. A partition separates the whole of the right side of the heart from the left; that between the auricles is thin, but that which divides the ventricles is thick and muscular.

It is, of course, necessary that each auricle should communicate with the corresponding ventricle, but the channel is guarded by a valve in each instance, which is so arranged as to allow of the passage of the blood from the auricle to the ventricle, but to prevent the retrograde course of the blood into the auricle, when the ventricle contracts. The orifices of the two great arteries, distributing blood to the lungs and to the body generally, are in like manner guarded, as these vessels emerge from their respective ventricles, by three semilunar folds of their lining membrane, which are forcibly brought into contact, on the elastic recoil of the artery succeeding its distension.

The action of the heart is rhythmical, *i.e.*, in regular order, the contraction of the auricles being succeeded immediately by that of the ventricles; and then there is a distinct pause before the auricles contract again.

If the ear be placed on the chest two distinct sounds will be heard to accompany the heart's action, and the pause, which is the heart's rest, may also be noted.

The throb of the heart against the side of the chest is due to the tilting of its loose apex at each contraction of the ventricles.

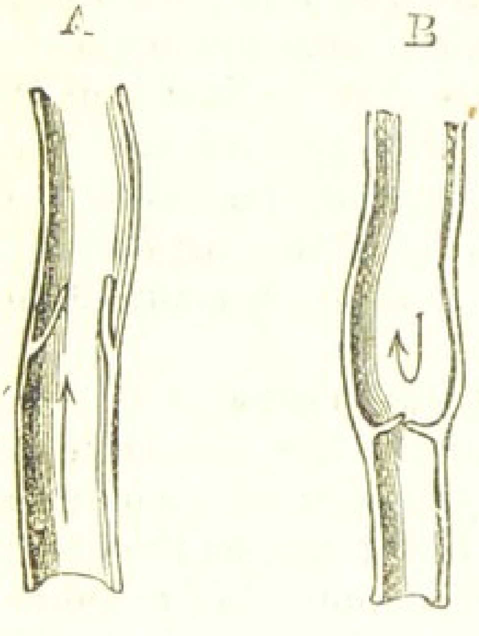
It is calculated that each ventricle is capable of containing about three ounces of blood, and the auricles not quite so much. This is the quantity pumped from each side of the heart at every beat; and as the adult pulse is about seventy-five in the minute, the quantity of blood thus circulated in a given time may be readily calculated. In early life the pulse is quicker, descending gradually from one hundred at three years old; and it is still slower in old age than in the prime of life.

Before considering the circulation as a whole, and the forces by which it is accomplished, it is requisite to describe the structure and properties of the blood-vessels.

There are, strictly, two sets of conduits for the blood, one of which conveys it from the centre or heart, and the other set conveys it back to the heart. But there is also a network of minute, hair-like tubes, of uniform calibre, which intervene between the extremities of the efferent * vessels or *arteries* and the afferent vessels or *veins ;* and these are the *capillaries*, which pervade every organised structure. Thus the capillaries are fed by the arteries, and the impure blood is returned from them by the veins.

The ARTERIES possess qualities which are but little needed in the veins, for the larger arteries are highly elastic, and the smaller branches are muscular ; therefore an artery is much thicker than a vein.

The VEINS resemble the arteries in their structure, but all their coats are thinner and feebler. The most remarkable peculiarity in these vessels is the presence of *valves*, the design of which is to prevent the reflux of the blood away from the heart, whilst they offer no obstruction to its progress towards the heart. It is because of the pressure to which veins are subjected that the valves are more numerous in the limbs ; indeed, there are but few in any of the veins which are not liable to muscular pressure, and they are altogether absent in many, as, for instance, in the brain, liver, and the interior of bones. It may, therefore, be readily understood that muscular pressure, when exercised on the veins, must assist the progress of the blood in the right direction, as it cannot force it backwards from the heart. Exercise is, in this way, a healthy stimulus to the circulation. When the veins become unnaturally dilated—varicose—the valves cannot act,



VALVES OF VEINS.

A. Valves opened by onward current.

B. Valves closed by regurgitant flow.

* See also page 95, where these same expressions are applied to nerves.

and artificial support is required to mitigate the evil consequences.

The CAPILLARIES form an intervening network between the extreme branches of the arteries and the commencement of the veins. They vary but little in their size, which very little exceeds that of the blood corpuscles. They are tubes, though their texture seems scarcely in the form of a membrane, but rather to consist of a soft yielding substance, with here and there nuclei; and through the walls thus constituted the plasma can exude, and even blood corpuscles may, under obstruction and pressure, escape without rupturing the tube. These vessels also absorb gas, or any soluble matter brought into relation with them.

The course of the blood may be easily understood by dividing the circulation into two distinct parts, or by describing it as represented by the figure 8. The pulmonary circulation is one division, in which the right side of the heart is alone concerned; the systemic circulation is the other, in which the left side of the heart is alone interested: practically the two sides might be entirely separated after birth; but before this period a communication exists between them, as the course of the blood through the lungs is not then needed.

The impure blood is collected from all parts of the body by the two great venæ cavæ, which pour it into the right auricle. When this cavity is distended it empties itself into the right ventricle, which propels the blood into the pulmonary artery, and thence through the lungs. From the lungs the blood is returned, in a purified state and changed in colour, to the left auricle; this in turn contracts and fills the left ventricle, from which it is driven through the aorta to all parts of the body. From the capillaries the blood is collected by the small veins, which unite to form the great branches that terminate in the venæ cavæ; but, in its progress upwards, there is a temporary diversion of a part of the current to undergo purification in the liver (see "Liver," p. 54). A similar diversion takes place in the aortic circulation to the kidneys (p. 61); and probably the spleen also effects some important changes in the blood which passes through it (see "Spleen," p. 56); but in these instances the veins return it at once to the heart.

In order to appreciate clearly the forces by which the circulation is accomplished, it is necessary to understand what are the obstacles to be overcome, and the different modes in which this is effected.

The distribution of the blood may appear to be more simple and easy than its collection from the distant parts to which it is dealt out; and this is, in a measure, true; for the obstacle offered by friction is necessarily greater where the surface is more extended, as in the smaller arteries and veins, and especially in the capillaries. But the interference with the uniform velocity of the current is compensated for by the increasing calibre of the vessels in the aggregate, and by the greater number and larger size of the veins. Moreover, it must be remembered that the two columns—that in the arteries and that in the veins—balance each other; that, in fact, the gravitation of the blood in the veins does not exist in healthy vessels, as an impediment to free movement towards the heart. Further, any temporary local obstruction is rendered unimportant by the free communication existing between the branches of the arteries, and more particularly between those of the veins.

Diagram of the Circulation.

A. Lungs. B. Heart. C. Liver. D. Spleen. E. Stomach and Intestines. F. Kidney (represented by a single organ). G. Pelvic Viscera (similarly represented). H. Upper extremity. I. Lower extremity. J. Head and neck.

1. *Vena cava superior*, containing venous blood, derived chiefly from head and neck, opening into right auricle (5).
2. *Vena cava inferior*, conveying blood derived from the lower extremities, kidneys, and pelvic organs, and receiving contents of hepatic veins (3).
3. *Hepatic Veins*, conveying blood from the liver.
4. *Portal Vein*, conveying blood from spleen and intestines to the liver.
5. *Right Auricle*, receiving blood from superior and inferior venæ cavæ, and transmitting it to (6) *Right Ventricle*, whence it is driven into (7) *Pulmonary Artery*, and conducted to the lungs; returning by (8, 8) *Pulmonary Veins* to (9) *Left Auricle*. The stream then enters (10) *Left Ventricle*, and is propelled through (11) *Aorta* into the arteries supplying the head and neck (12), the upper extremities (13, 13), digestive organs (14), kidneys (15), pelvic organs (16), and lower extremities (17, 17).

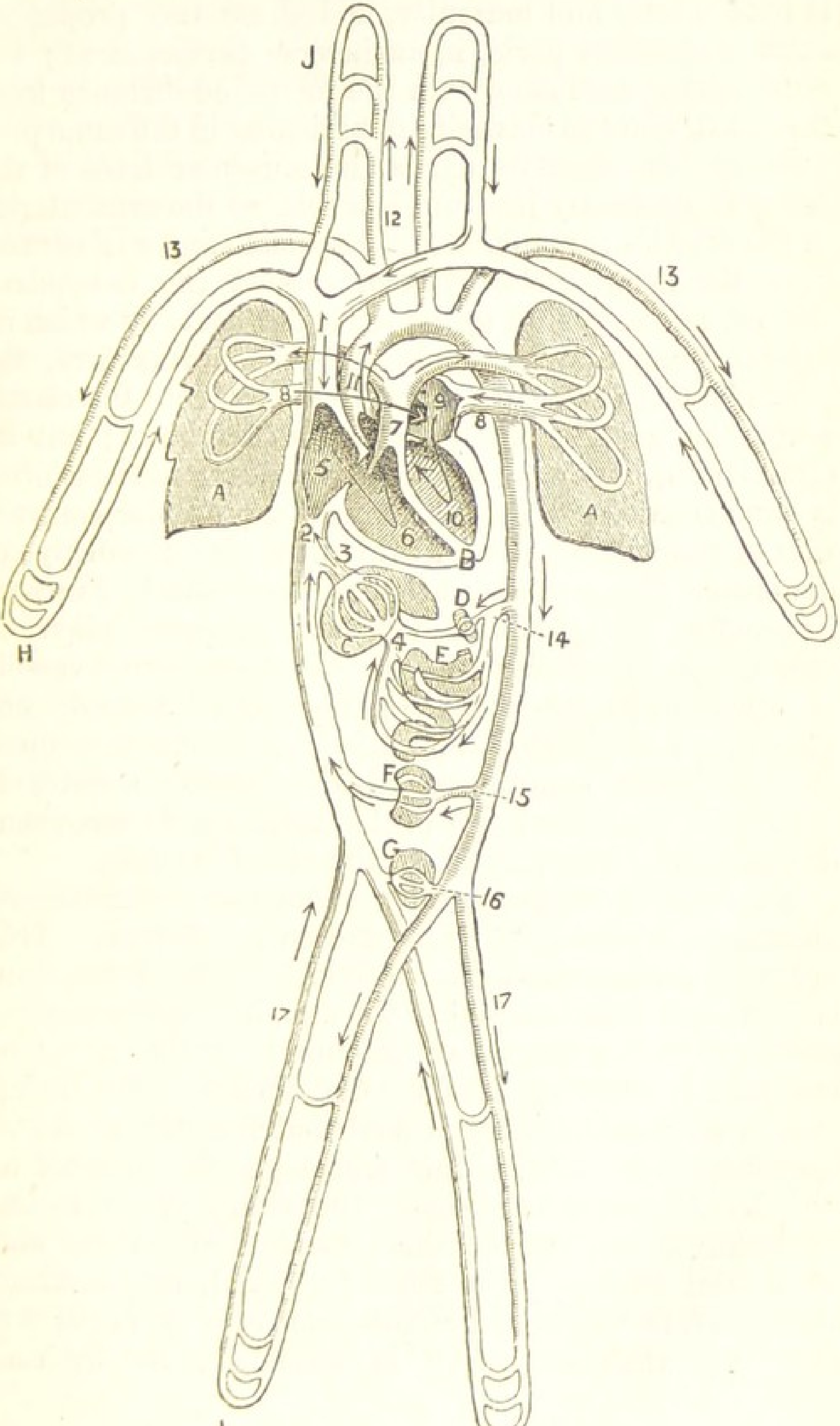


Diagram of the Circulation.

It has been remarked that the texture of the arteries is both elastic and muscular, and these two properties exist at different parts, in an inverse development; the muscularity increasing with the increased distance from the heart, and the elasticity diminishing in the same proportion. In other words, as the muscular force of the heart is gradually less and less felt, so the muscularity of the arteries is augmented. A special supply of nerves, from the sympathetic system,* called the *vaso-motor* nerves, is distributed to the muscular coat, by which its active agency may be regulated. When, therefore, the powerful left ventricle propels the blood into the elastic aorta, the impulse is felt throughout the body; but its diminishing power, as the blood recedes from the centre, is compensated for by the increasing muscular contraction of the arteries; and in this way, also, the degree of distension of the smaller arteries is controlled. Further, in proof of the part this muscular property plays, it may be remarked that it is more developed in the vessels of organs which are at some periods more actively engaged than at others. The influence of emotion upon the muscular contraction of the smaller arteries is evinced in the suspension of this action, and consequent dilatation of these vessels, in the act of blushing.

The uses of an elastic tube, under the circumstances described, must be, in great measure, obvious. This property enables the artery to yield to the force from behind, and thus to equalise the amount of pressure resulting from the heart's contraction; by the recoil of the vessel, after distension, the aortic valves being closed, an active agency is contributed to the forces of the circulation. When this property is deteriorated or lost, by degenerative disease, the artery yields to the distending force, and becomes the seat of serious and often fatal disease. On the other hand, this contractility, both in length and circumference, is an important safeguard when an artery is wounded; for by this

* See page 96.

change, and by the coagulation of the blood which it facilitates, an open vessel is closed and sealed.

The impulse of the heart's contraction, combined with the elastic contractility of the artery, is the cause of the pulse; which consists in an actual dilatation in the calibre of the artery, followed by its elastic recoil. The *intensity* of this force varies with that of the left ventricle, and may be increased by the active contraction of the artery in a part that is, for instance, inflamed; but the *number* of the pulse must almost correspond with that of the heart's contraction. It is thus that we judge of the general condition of the system, by testing in this way the power and frequency of the heart's action; and an interesting instrument has been invented, by which tracings of the pulse may be taken, and variations noted, with much more delicacy than can can be done with the finger.

The current of blood through the veins is maintained by the constant pressure from behind, originating in the contraction of the ventricle; this is felt throughout the venous system. Each auricle is gradually filled by the blood flowing in from the great veins; and the force of this current, together with the muscular contractility of the veins near the heart, are sufficient to prevent regurgitation into these vessels during the comparatively feeble contraction of the auricle. No doubt the activity of the smaller arteries aids in propelling the blood onwards through the veins. The slight muscularity of the veins themselves can help but little, and it is doubtful whether the capillaries exercise any influence in promoting the movement; but the muscles of the limbs are important agents in this respect, and various experiments and observations seem to prove that the act of drawing the air into the lungs facilitates the passage of the venous blood towards the heart. The suctional property of the tissues, exercised in abstracting nutriment, probably assists in stimulating the active movement of the blood in the capillaries.

SECTION VIII.

RESPIRATION, THE VOICE, &c.

THE unceasing waste, and the deterioration in the quality of the blood, demand an equally constant renewal and purification. The loss is supplied, as already described, by the assimilation of new material; and the liver and kidneys act in the removal of impurities; but the chief agents in the latter respect are the lungs. These are excretory organs in function and in structure, for they abstract carbonic acid from the blood, and it is expelled through their common duct, the trachea or air-tube; but they also perform the further important office of introducing a new and important element —oxygen—into the circulation.

In considering the function of the lungs, it will be necessary to give attention separately to the structure of the various parts concerned in breathing, to the mechanism by which we breathe, and to the changes which are produced in the blood and in the air by breathing.

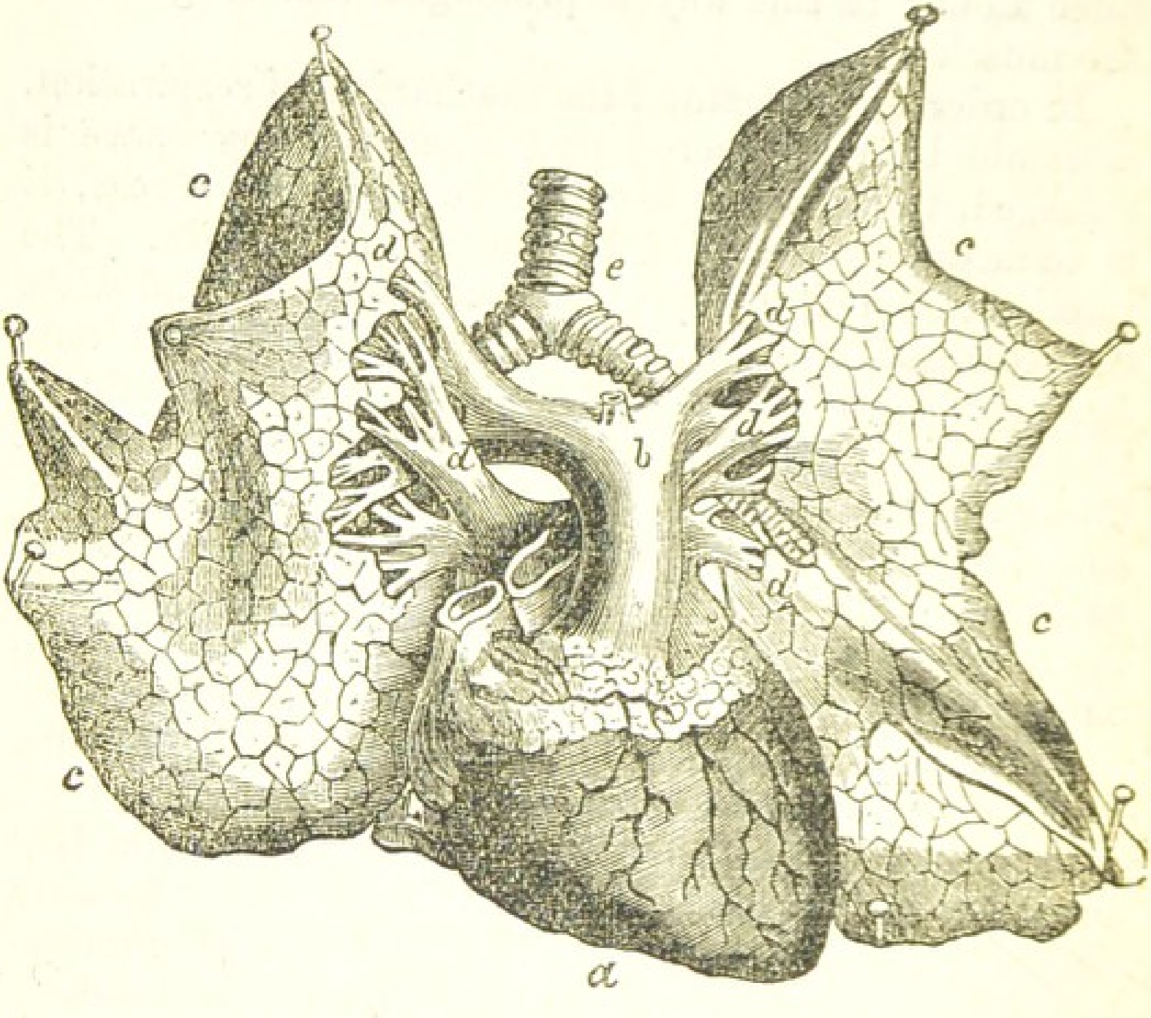
The CHEST, or *thorax*, which contains the heart and lungs, is a conical cavity, narrow above and broad below. It is separated, as already noticed, from the abdomen by the great muscular partition called the *diaphragm*. The walls of the chest are formed by the ribs, and the muscles which occupy the spaces between them—the *intercostals*. The diaphragm is arched with its convexity directed upwards, and its circumference is attached to the movable ribs. These curved bones are connected by joints to the spine behind, and in front to the breast-bone through strips of intervening elastic cartilage. Thus, when the ribs are fixed or raised by the action of the intercostal muscles, the contraction of the diaphragm presses down the viscera of the abdomen, and in this way enlarges the chest.

The entire act of breathing is called *respiration;* but the in-drawing of the air is distinguished by the word *inspiration*, and the expulsion of the air is called *expiration.* It is necessary these alternate acts should be performed, and that there should be as much economy of muscular effort as possible; therefore, we find that the expulsion of the air is usually accomplished by elastic force alone; in this way a prolonged rest is given to the muscles.

In order to understand the mechanism of respiration, it should be remembered that whenever any space is enlarged, to which the atmosphere alone has access, it is immediately occupied by the air rushing in. The interior of the chest represents such a space; and when it is enlarged, the atmospheric air enters by the only apertures open to it, viz., the mouth and nose, and in this way occupies what would be otherwise the vacant interior of the lungs. This effect is due to the atmospheric pressure, which is equivalent to fifteen pounds on every square inch; and the interior of the lungs is the only space which can be influenced, under natural circumstances, by the expansion of the chest.

From this statement, then, it is evident that the interior of the LUNGS must be hollow; and that their exterior must fit so accurately to the chest-walls that there is no space between them. Yet the lung is not a single bag or sac, but its interior consists of numberless little bags, called air-cells, of infinite minuteness. As it has been calculated that there are very many millions of these cells, it may be readily conceived what a very large extent of surface they must present in the aggregate; and with this entire surface some fresh air comes into contact continually as we breathe. But again, every cell is covered by the terminations of minute arteries, capillaries, and veins; and thus a vast quantity of blood is constantly, at each beat of the heart, distributed over these cells. In this we find an explanation of the arrangement described—the purpose being to bring into close relation the blood and the atmospheric air we breathe, whereby the former is purified at the expense of the latter.

The interior of the chest is capacious, and the size of the two lungs, which occupy the greater part of it, considerable. The form of each lung corresponds to that of each side of the chest, being conical with its



a. The heart. *b*. Pulmonary artery. *c, c, c*. The lungs spread out. *d, d, d, d*. The Pulmonary veins. *e*. The trachea.

base or broad part below. The right lung is rather shorter and higher than the left; they both overlap the bag surrounding the heart. These organs are very light in weight, and have a bluish or grey mottled appearance. Their exterior is covered by a serous membrane —the *pleura*—which also lines the walls of the chest;

and in this way the easy movement of the lungs is secured in respiration.

As there is necessarily a communication existing between the myriads of air-cells and the chief air-tube—the *trachea*—this is effected by the division of the tube into a branch for either lung; and these—the *bronchi*—again divide and subdivide, until they finally terminate in the cells. When the lung is cut across, it appears and feels like a piece of sponge containing air and fluid mixed.

On making a more careful examination of the texture of the lung, it is found divided into small lobules, each of which consists of cavities or air-cells, varying in size, but averaging about one-hundredth of an inch in diameter, and clustering around a delicate air-passage, and communicating with each other, or directly with this inter-cellular passage. The larger air-tubes and small bronchi are lined with epithelium. The bronchial tubes contain muscular fibre, and are, therefore, contractile, and the texture of the lung is elastic; both these properties are exercised in the act of expiration; but it is the latter which is the special antagonist of the diaphragm; for when this muscle is at rest, the elastic force of the lungs expels the air from them, until resisted by the arched tension of the diaphragm; and in inspiration the effort of the latter is directed to overcoming this elastic force; so that natural respiration is performed by the alternate predominance of these balanced forces, with but little assistance from other sources.

The ordinary acts of respiration are performed independently of the will; but we are able to exercise volition in both inspiration and expiration. In ordinary inspiration, probably the diaphragm and intercostal muscles alone act; the contraction of the former, by converting its convex into a plain surface, increases the capacity of the chest, at the expense of that of the abdomen; whilst the intercostal muscles enable it to do this by raising the ribs, and thus preventing the diaphragm from drawing them in. Thus the air is sucked in to occupy the enlarged space, and fills the air-cells.

We thus have the air and the blood brought into relation over a vast extent of surface, with the interposition only of the thin wall of the capillary vessels, and the delicate texture of the air-cells; and here the changes take place by which the blood is purified. In order to comprehend how this is effected, it is necessary that the reader should be informed or reminded that fluids can hold gases in solution, and that when a fluid so charged is brought into relation with another gas, though a permeable membrane be interposed, an interchange of the gases takes place. Moreover, that when two different gases are brought into contact, there is a similar interchange. In accordance with the former of these laws, the blood gives off its carbonic acid and imbibes oxygen; in accordance with the latter, the newly-inspired air mingles with that which remains, after each expiration, in the lungs.

It has been remarked that carbonic acid, or gas consisting of carbon and oxygen in combination, is produced by the constant waste which is going on throughout the system generally, that is, in the various textures, and also in the blood itself; the carbon being, in fact, the product of this organic combustion, and combining with the oxygen which has been conveyed to it by the blood. Thus carbonic acid is taken up by the capillaries throughout the frame, in exchange for the oxygen which is carried to it by the arteries; and the veins carry back to the right side of the heart the dark deteriorated blood, charged with carbonic acid. It is thence propelled into the lungs, where the interchange is reversed; *i.e.*, the blood yields carbonic acid, which is expelled by the air-tube, and absorbs oxygen from the freshly-inspired air. That the change of colour in the blood is caused by this interchange of gases is ascertained from experiment; but on what it immediately depends is not decisively known, though it is supposed to be due to the degree of oxidation rather than to physical causes.

The lungs are never emptied of their air, for they are capable of containing between two hundred and three hundred cubic inches, and at each ordinary respiration not more than about twenty-five or thirty inches are breathed; as the freshly-inspired air cannot displace that already in the lung, it follows that the law just mentioned, in reference to the diffusion of gases (p. 78), must come into operation, in order that the gaseous interchange already noticed should occur, and this is promoted, as is also the diffusion of heat in the mixed air, by the movements of the vibratile cilia in the small bronchi. Yet we are able, by forcibly expiring, to expel more air than is usually got rid of; and, on the other hand, we may draw in an unusual quantity of air by taking a deep breath. Different names have been used to designate these various conditions; thus, the quantity of air left in the lung after an ordinary expiration is called the *supplemental* air; that which remains after a forced expiration, the *residual* air; that by which the chest is filled, after a deep inspiration, over and above the ordinary quantity, is known as the *complemental* air; and the *tidal* air is that which, as it were, ebbs and flows at each respiration.

Ordinary respiration, in health, is repeated about fourteen or fifteen times every minute, a period of repose succeeding each expiration. If thirty cubic inches of air be drawn in at each respiration, the quantity inspired in an hour would amount to about twenty-six thousand cubic inches; and when we take into account that the entire quantity of blood in the body probably passes the round of the circulation in between two and three minutes, it is readily conceivable how the blood may become impregnated with poison existing in the atmosphere, even in infinitesimally small quantities.

Although oxygen is the supporter of life, in the way described, it cannot be respired in a state of purity; therefore it is diluted with another gas—nitrogen—which seems to be employed, in this instance, simply as a vehicle, as it undergoes very little, though somewhat variable, change in quantity by the act of breathing. The proportion in one hundred parts is seventy-nine of nitrogen to twenty-one of oxygen; the proportion of carbonic acid in the atmosphere does not exceed one in two thousand.

The CHANGES which occur in the AIR, by respiration, are that it loses about five per cent. in oxygen, and receives nearly the same quantity of carbonic acid; there is a trifling excess of oxygen which is absorbed, and probably combined with hydrogen to form water. The temperature of the expired air is from 90° to 100° Fahrenheit; and it is saturated with vapour, which amounts to about ten ounces of water in twenty-four hours. The quantity of pure carbon, thus eliminated in this time, has been calculated at about eight ounces; rather more is exhaled by day than by night, in cold than in hot weather, and after food and exercise.

The CHANGES which take place in the BLOOD by respiration are, as already stated, that its colour is converted from a deep purple to a bright scarlet; that it has exchanged carbonic acid for oxygen; that it is raised in temperature one or two degrees, and that it contains more fibrin and coagulates more firmly.

It may naturally occur to the reader, that the continual consumption of oxygen and substitution of carbonic acid must disturb the balance in the atmosphere, necessary for sustaining animal life; and such would be the case were it not for the compensating agency of vegetable life in restoring the balance. Carbonic acid is essential to plants, the structure of which contains so much carbon; and under the influence of the sun their leaves absorb this gas; and, taking up the element they need, they give out oxygen, retaining, however, sufficient, with their other food—especially ammonia and water—to form the various compounds of which they consist, and which serve as nutriment to animal life; such as sugar, starch, gluten, &c. Thus, it will be perceived that in vegetables, the process which has been described as animal combustion is reversed, and the supporter of that combustion—oxygen—is separated and supplied; and latent heat, derived from the sun, is also stored, according to the theory already mentioned (see p. 11), to be reproduced at a future time by the combustion of wood and coal.

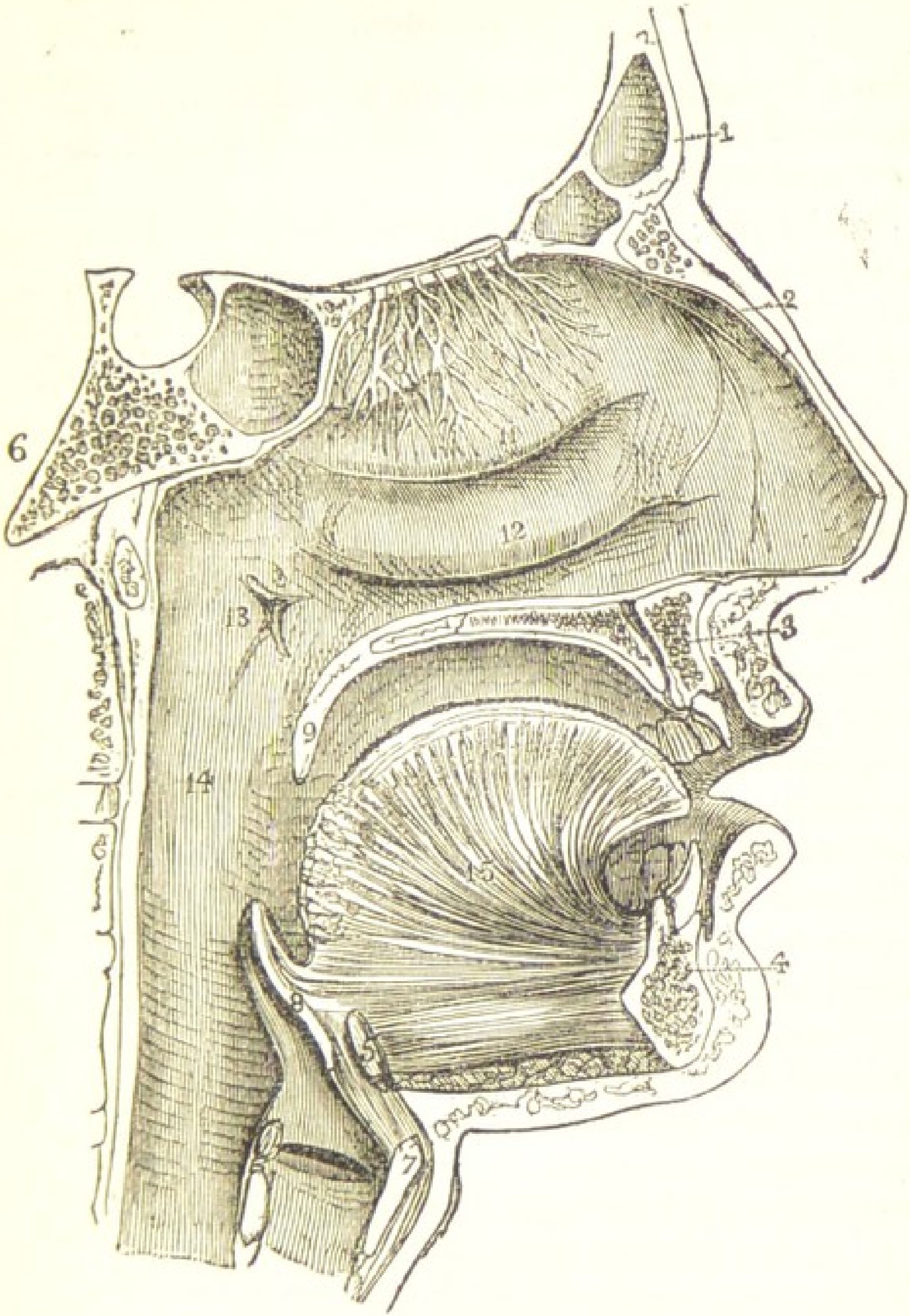
The same process goes on in both fresh and salt water, which hold oxygen in solution; for the presence of this gas is essential also to sustain the life of fish; and water plants yield it, whilst they likewise absorb the carbonic acid which is the product of the respiration of fish.

What has been said respecting the function of the lungs cannot fail to carry with it the lesson of the importance of pure air to breathe, and, therefore, of the free ventilation of the apartments in which we live, and the exclusion of noxious gases. We further learn that mischief results rather from the gradual and insidious introduction of such poison, in a very diluted form and for a lengthened period, than from exposure to a more concentrated poison for a brief time, when the warning notice of its presence serves as a caution against its continued inhalation. These remarks apply rather to the ordinary impurities that are met with in the atmosphere than to specific and infectious poisons, which may be imbibed through the lungs or by the alimentary canal; for, as already remarked, fluid is rapidly absorbed by the stomach and intestines (p. 57).

Of the fatal effect of breathing air impregnated largely with carbonic acid, we have many instances in the *choke-damp,* as it is called, of coal mines, and in the bottom of stagnant wells; and a terrible exemplification of it is recorded in the catastrophe of the Black Hole at Calcutta. Happily a test of the purity of air from such fatal excess of carbonic acid gas is afforded in the circumstance that oxygen is equally important as a supporter of combustion; and when it is replaced by carbonic acid a lighted candle is immediately extinguished.

Immersion in carbonic acid has the same effect as immersion in water, and attempts at resuscitation should be practised in the same way in either case, or when breathing is suddenly suspended from any similar cause. The patient should be placed on his back, with the shoulders supported; and the tongue should be drawn forwards, so as to keep open the orifice of the windpipe. The operator must then grasp the arms just above the elbows, and draw them upwards until they nearly meet above the head, and then immediately lower and replace them by the side; the chest is thus expanded. This is to be followed directly by moderate pressure with both hands on the lower part of the breast-bone; and the process is to be repeated twelve or fourteen times in a minute. Cold and warm water may be alternately dashed in the face from time to time, to rouse an effort at inspiration; and the warmth of the surface must be maintained by friction and warm clothing. In drowning, the patient should first be placed with the face downwards, and lower than the feet, for a few seconds, to allow the water to drain from the lungs; this may be done on an inclined table or board; and the desired effect will be facilitated by drawing the tongue forwards and gently pressing on the back. Success has attended even very prolonged efforts. The condition produced by the causes mentioned is technically called *asphyxia*.

The influence of agents by which insensibility to pain is produced—anæsthetics, as they are termed—is due to the absorption of a vapour or gas into the blood, when it is breathed, mixed with the atmosphere, and so permitted to exercise its effect on the brain. The important precaution in administering chloroform, when otherwise safe, is to secure a proper dilution of the vapour by admixture with the atmospheric air.



SECTION OF NASAL FOSSÆ, LARYNX, &C.

1. Frontal bone and sinuses.
2. Nasal bone.
3. Superior maxillary bone.
4. Inferior ditto.
5. Hyoid bone.
6. Portion of base of cranium.
7. Thyroid cartilage.
8. Epiglottis.
9. Uvula and soft palate.
10. Superior turbinated bone.
11. Middle turbinated bone. On these are distributed filaments of the olfactory nerves.
12. Inferior turbinated bone, in front of which are filaments of the nerve of common sensation.
13. Orifice of Eustachian tube.
14. Pharynx.
15. Tongue.

THE VOICE.

Two subjects still remain for consideration, which are associated with respiration, viz., the voice and the production of animal heat.

The Voice. The upper part of the air-tube, called the *larynx*, has been already mentioned in connection with swallowing (p. 49) and breathing (p. 75); a more particular description is required to understand its agency in connection with the voice (see diagram, p. 83).

It consists of a broad cartilage—the *thyroid*—which forms the chief projection of the throat, and is much more prominent in men than in women.

Below this is an annular cartilage—the *cricoid*—which is connected below to the *trachea*. Behind the thyroid, and close to the aperture of the air-tube or *glottis*, are two small movable cartilages, the *arytenoid;* and between these and the angle formed by the two sides of the thyroid, two cords are stretched, which are, therefore, close together in front, but separated, more or less, behind. The space left between them is called the *chink*, or *rima* of the glottis.

Now, as the back extremities of these cords are connected to the movable arytenoid cartilages, it follows that every movement of the latter influences the former; and as there are numerous small muscles attached to the arytenoid cartilages and others to the thyroid, they are capable, by their action, of opening more widely the chink of the glottis, and also of making more or less tense the *vocal chords*, as they are called. These chords are relaxed in ordinary breathing, and, therefore, give out no sound; but when they are made tense enough they vibrate, as air passes over them, so as to produce a sound, varying in its note with the degree of tension; and it is thus that the *voice* is produced.

The voice varies in different persons according to the size and other qualities of the larynx; and is deeper in men than women, because the larynx is constructed on a larger scale.

Speech, or articulation, is the modulation of the voice by the mouth and nose.

The resonance of the voice is produced by the arched form of the palate and by the cavity of the nostrils; when the air is shut out from the latter, by closing the nostrils either in front or behind, a disagreeable effect is produced, absurdly enough called "speaking through the nose." If the palate, or roof of the mouth, is defective, articulation is scarcely intelligible.

The tongue is proverbially the organ of speech, yet it is only part of a complicated apparatus by which sounds are modulated.

The varying relation of the tip of the tongue to the palate assists importantly in articulation, as in the pronunciation of D, G, J, L, N, T. The vowels are articulated by the varied form of the aperture of the mouth produced by the altered position of the lips. C and S, as well as X and Z, are produced by expelling the air rapidly through the front teeth; and lisping is the result of interposing the tongue. F and V are pronounced between the upper incisor teeth and the lower lip. R is sounded by the vibration of the tip of the tongue. B and P are explosive consonants, *i.e.*, produced by the sudden separation of the lips when the air is forced against them. The art of ventriloquism depends on the cleverness of the actor, in so modulating the voice, and muffling it, so to speak, as to give the impression of its proceeding from some given direction, which is indicated by gesticulation, and from a distance or near at hand, as the case may be.

Although the tongue has such multifarious offices, the greater part of this organ has been removed by operation, with more impunity than might have been anticipated. It is a delicate organ of touch and of taste; it aids importantly in articulation and deglutition, as well as in the mastication of the food; yet most of these functions have been partially performed, after removal of a great part of the tongue; and even articulation has not been so interfered with as to become unintelligible.

ANIMAL HEAT.

The generation of animal heat, as a function of respiration, is not less essential to the promotion of development and the support of life, than the interchange of gases already described. The average temperature of the adult human body, which is subject to slight variations even in health, is about 100 degrees; in childhood it is one or two degrees higher. But the surface, which is exposed to the air and to evaporation, is cooler. The temperature varies somewhat through the day, and is a little lower at night.

The variations in disease are considerable, and constitute an important branch of medical study. Usually the temperature sinks prior to death, but sometimes it is raised many degrees—as many as eight or ten—above the natural standard; occasionally considerable time elapses after death before the temperature sinks.

During hybernation, when the respiration of the animal is feeble and slow, the temperature sinks proportionally.

The peculiarity of cold-blooded animals, as distinguished from warm-blooded, is that their temperature varies with that of the surrounding atmosphere.

Artificial assistance enables man to adapt himself to any climate; but the power of generating heat would seem to vary in animals, and thus fit them to live in different climates, even apart from the variety of natural clothing with which they are provided, and the food best adapted to sustain them. (See "Digestion," p. 46.)

The generation of heat in the animal body is not dependent directly on any external agency, and is a purely chemical process, exemplifying in a remarkable way the application and economy of means in the attainment of a particular end; for the very process by which carbon is disengaged and rendered miscible with the blood, is that by which heat is developed in a diffused and regulated way throughout the system.

In order to comprehend how this result is obtained, it is necessary to mention that a combination between certain elementary substances to form a new compound, is accompanied by the evolution of heat or transformation of force; condensation likewise occurring. Carbon and oxygen represent two such elements, and so do hydrogen and oxygen; their respective combination to form carbonic acid and water is accompanied by condensation, and they occupy less space when combined than when separate; heat is evolved in this process. Similar phenomena are witnessed, with a similar result, in the combustion of wood or coal, in an ordinary fire.

The sources from which all these elements are obtained has been already noticed, viz., from the food, the lungs, and the waste of tissue; and the combination of these elements, and, therefore, the evolution of heat, take place wherever there are capillary vessels, *i.e.*, in the most diffused way throughout the whole system and in all the tissues, so that one part shall not be hotter than another. But it may be readily understood how some particular part which is the seat of inflammation, and, therefore, in which the circulation and tissue changes are more active, is correspondingly raised in temperature; or, again, that in fevers and some other diseases, the temperature rises *generally* for the same reason.

Respiration, therefore, has for its object the oxidation of the carbon and hydrogen, by which force or energy is liberated chiefly in the form of heat. The carbon and hydrogen are imbibed in the form of food; the oxygen is breathed; and the quantity of heat generated in respiration is represented by the equivalent of carbonic acid and watery vapour exhaled. The food which affords the chief supply of heat is that which requires most oxidation, or, in other words, which contains most hydrogen and carbon, as oil or fat; and this is the least available for the formation of tissue.

Moreover, heat is evolved by the oxidation of compounds which are the product of degeneration or waste of tissues, as urea in the kidney and, possibly, glycogen, a substance from which sugar is generated in the liver.

The carbonaceous matter not required for heat by oxidation is stored as fat; and this is usually most abundant in those who take little active exercise, for muscular action evolves heat, and thus consumes the heat-producing or combustible elements; exercise also requires more active respiration to supply oxygen for this purpose, as well as more free perspiration from the surface to moderate the heightened temperature.

Formerly the nervous system was accredited with much direct, though unexplained, influence in the evolution of heat; and this opinion was founded on the undoubted fact that parts in which this influence is defective, as in paralysis and loss of sensation, are usually colder than where the nerve-power is unimpaired. Yet, it may be easily conceived that this relation is indirect, as the vital energy is necessarily deficient under such circumstances; and the organic functions are depressed, so that the molecular changes which generate heat are sluggish and imperfect. It is more consistent with our present knowledge to conclude that animal heat is directly dependent on the chemical agency alone which has been described.

The temperature of the surface is much more rapidly reduced by a current of air than in a still atmosphere, as it acts just as a current of water would, by constantly changing the surrounding fluid in contact with the body, from which the heat is thus abstracted more quickly. Even a very low temperature can be borne with little inconvenience when the air is still, because there is but little disturbance of the partially-warmed air in immediate contact with the surface of the body. A brisk wind at fifty degrees will chill any one exposed to it more than a still air at thirty degrees. Evaporation by perspiration lowers the temperature.

In early life and old age the body is more susceptible to causes tending to lower the temperature. Warm clothing of non-conducting material next to the skin should never be neglected in this changeable climate, and especially so in the young and aged.

SECTION IX.

THE NERVOUS SYSTEM.

FREQUENT reference has been made to the nerve centres as presiding over and directing the functions of various organs, through the medium of nerve-cords, which communicate, like a set of telegraph wires, between the galvanic centre and the various distant points to which they are distributed. In the present section, a brief account will be given of the component parts of the nervous system, and of their several offices: the nature of the nerve-force itself is purely conjectural, and we know nothing of its mode of acting beyond the results which we witness.

The essential parts of the nervous system are, centres which generate nerve-force, or nervous influence as it is also often called, and nerve-cords, or nerves, which communicate between these centres and various parts of the body.

The *vesicular* portion of the nerve-matter, which is abundant in the nerve-centres, presents generally a greyish-red appearance in the mass, and is composed of cells. The fibrous portion is really tubular, and the tubes contain a transparent matter, which becomes opaque and white after death (see "Tissues," p. 17).

Of such simple materials are the instruments constituted, through the agency of which such great results are obtained.

The nerve-tubes or fibres are packed in bundles, and the aggregation of the bundles constitutes the nerve-trunk. This packing arrangement is for convenience in distribution; for every ultimate fibril preserves its identity, and runs its course without intermingling with others from its commencement to its termination. This is essential to prevent confusion of impressions; and a nerve-fibril, wounded by the point of the finest needle at the extremity of the finger, conducts the impression unerringly to the brain. There is a close and obvious analogy between the arrangement here described, and the battery and wires used in telegraphy.

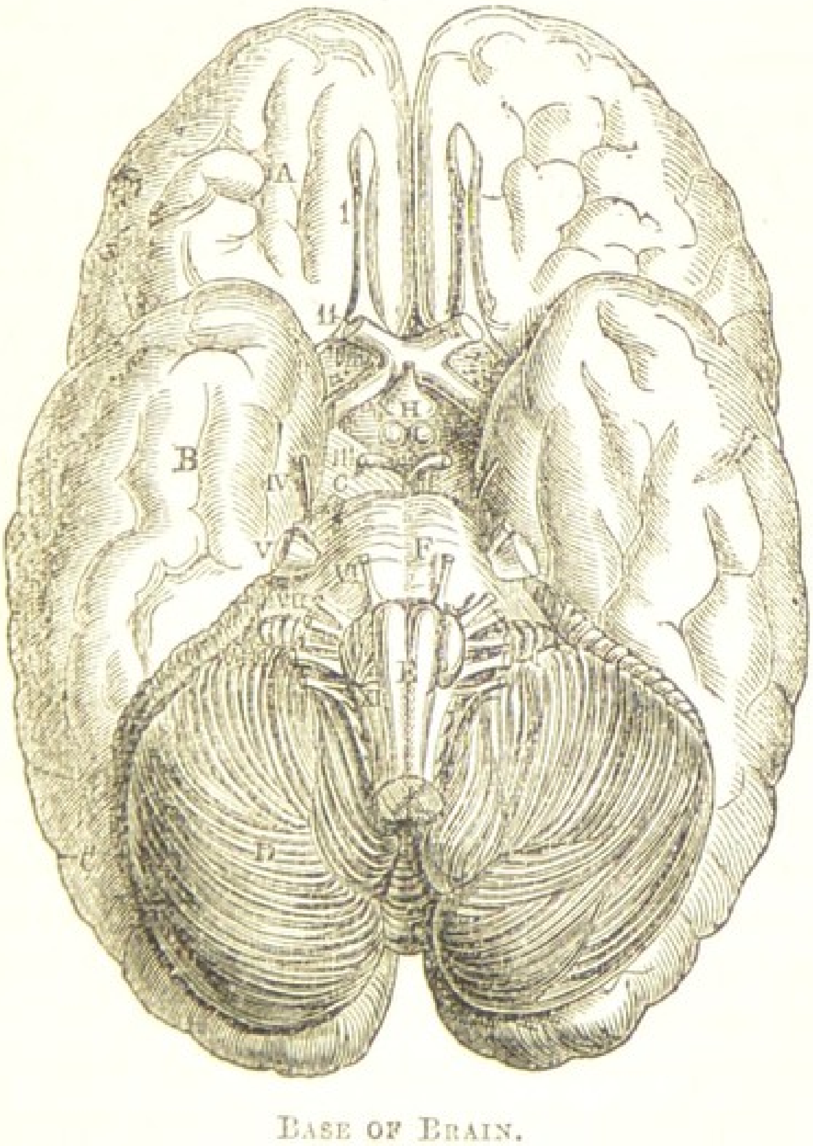
A brief account will now be given of the anatomy of the nerve-centres and nerves, before alluding to their respective functions.

The CEREBRO-SPINAL system consists of the brain, the spinal cord, and the nerves emanating from them. The brain occupies the interior of the skull, and the shape of each is moulded to that of the other. The whole interior of the space, in which the brain is lodged, is lined by a dense fibrous membrane, the *Dura Mater*, which lodges the vessels for the supply of blood to the inner surface of the bone, and sends processes or partitions in different directions, to separate various parts of the brain from each other and afford them support. The bottom, or *base* of the skull, is perforated by a great many holes, for the transmission of vessels, and of the nerves which spring from the brain, which are thence called *cerebral*. One large round hole near the centre, in the occipital bone, is for the prolongation of the spinal cord from the brain into the spinal canal, which is formed by the union of the vertebræ to each other (see p. 23), and continued along the sacrum. This canal is also lined by dura mater, and presents a series of round holes, or outlets, in pairs, completed by the conjunction of each two adjoining vertebræ, and in the sacrum, and giving passage to the thirty-one pairs of spinal nerves (p. 21).

The brain and spinal cord are covered directly by a vascular membrane, called the *pia mater*, which is delicate, and dips down between the foldings of the brain, but is thicker over the cord; outside this, and intervening between it and the dura mater, is the double layer of a serous membrane called the *arachnoid*.

The brain and spinal cord are divided, symmetrically, in the middle line, for the special supply of nerve-force to either side of the head, body, and limbs: this is proved by experiment and accidental injuries. But the latter also seem to demonstrate that there is a duality in the function of the brain in its association with the mental faculties; for *one* side may be seriously injured, without corresponding impairment of intellectual activity.

The *brain* is divided into a larger and smaller portion,



BASE OF BRAIN.

A. Anterior lobe of cerebrum.
B. Middle ditto.
C. Posterior ditto.
D. Cerebellum.
E. Medulla oblongata.
F. Pons varolii.
G. Crura cerebri.
H. Interpeduncular space.
I. to IX. The nine pairs of cerebral nerves.

named, respectively, *cerebrum* and *cerebellum*. These are connected, as regards their lateral halves, as well as to each other and to the spinal cord, by fibrous nerve bands, some of which are termed *commissures*.

The exterior of both cerebrum and cerebellum consists of grey matter, and the interior of white. The cerebrum is arranged in tortuous folds, which are termed convolutions, but the cerebellum has more of a simple folded appearance on the surface, like the leaves of a book.

The brain is plentifully supplied with blood, and many arrangements exist to obviate the risk of pressure from its accumulation within the skull, or the ill consequences resulting from a deficient supply: these are chiefly the many sources of supply, the free communication between them, and the lodgment of the large veins in resisting canals within the folds of the dura mater. Moreover, the fluid within the brain, and on the exterior of it and the spinal cord, which forms a sort of water-bed, varies in position and quantity, according to circumstances.

The spinal nerves are attached to the cord by two sets of roots, anterior and posterior; and at the line of their attachment the cord is grooved by two parallel lines through its whole length. The anterior roots are those which communicate motor power to the muscles; the posterior convey sensation to the brain. Both roots cross to the opposite side of the cord, but at different parts: thus, injury or disease of one hemisphere or side of the brain affects the opposite side of the body.

The grey matter in the interior of the cord is supposed to be associated with the transmission of these sensory impressions; but it is probably also, and chiefly, the centre of that reflex action which is resident in the cord and not dependent on the brain. (See p. 96.)

The upper, expanded portion of the spinal cord is called the *medulla oblongata;* it likewise contains grey matter in its interior, which is specially allied with the act of breathing.

The *cerebellum* rests in the posterior, or deepest compartment of the skull, and is connected with the cerebrum and medulla oblongata. When a section is made of the cerebellum, it is found to be composed of grey matter externally, in the midst of which the white fibrous matter spreads out something like the branches of a tree.

Lastly, the *cerebrum* has its two hemispheres, or lateral halves, separated by a perpendicular partition of dura mater, which descends to the great commissure which is called corpus callosum. The pia mater, or vascular membrane, dips into the intervals between the convolutions, and thus is brought into contact with a very large surface of grey matter, in the interior of which the white matter is spread out, but without presenting the arborescent appearance described in the cerebellum.

The cerebellum is believed to possess the property of harmonising the various movements of the body—an important office, when we consider the multiplicity and complexity of muscular actions required in the performance of so many acts.

Respecting the functions of the cerebrum, some few things are known with the certainty which is derived from experiment; but very much is purely conjectural. Thus, we know that the power of willing any muscular movement emanates from the cerebrum, and that common and specific sensations are resident in it likewise.

Yet there remains the great bulk of the cerebral hemispheres to be accounted for. It is the large size of this part that especially characterises man's brain. And not only so; intelligence in the higher animals is accompanied by a proportionate *relative* development of the cerebral hemispheres. Further, in different races, and even individuals, the same fact is observed. The natural conclusion to which these observations point is that there is an association between the higher faculties of the mind, such as reflection, reasoning, memory, &c., as well as the emotions, and the great cerebral mass which fills the upper part of the skull. This supposition is supported by the observed fact, that defective development of this portion of the brain is accompanied by corresponding deficiency in intellectual capacity, most remarkably exemplified in idiots; also by the fact that pressure on the brain resulting from injury or disease, and thus communicated to the whole mass, completely suspends all intellectual power, including perception and volition. But if one hemisphere only be injured, the other, if not compressed, seems capable of performing its intellectual functions, at any rate for a time. Whether special faculties of the mind are associated with special parts of the brain has not been satisfactorily proved, though some hold the opinion very decidedly that such is the case. Probably it may be so to a limited extent; at least, there is nothing physiologically inconsistent with such a supposition.

Many circumstances, especially in disease, seem to be suggestive of functional inequality in the two cerebral hemispheres. The left side is supposed to excel the right, by virtue of its receiving, as some assert is the case, a larger supply of blood; just as the right arm is supposed to owe its greater strength and aptitude to the same cause.

Before this subject is dismissed, it may be remarked, that its discussion has nothing in common with what is usually termed materialism.

It cannot be denied that the intellect is associated with the brain, and is influenced by physical changes in this organ: we have no alternative but to accept this unquestionable fact. What the nature of that association may be, and how mind and matter are thus brought into relation, we do not know. The necessity for such relation must be evident, when we consider that, unless brought into contact, so to speak, with material objects through a material agency, the mind must be a blank. The way in which this contact is established is through the medium of the senses; and no conception or idea of the external world could be formed, without perception through the senses. If we could imagine a human being existing without any sense, whereby a single perception could be awakened, the mind must remain a blank. But a recognition of the association between the material and immaterial parts of our nature, is very different from affirming that the latter is derived from the former; that the mind holds the same relation to the brain as the bile does to the liver. This is a purely gratuitous assertion, and cannot be sustained by any physiological analogy, and has nothing to commend it to our common sense. There are the strongest reasons why this temporary association should exist. It is wonderful; one of the most inscrutable of the many truths presented for our acceptance without our comprehension; we can but believe and wonder, whilst we recognise this proof of creative power and wisdom.

The NERVE-CORDS, derived from the *cerebro-spinal* centre, are distributed throughout the body, often accompanying the large blood-vessels, especially in the limbs.

They have been already mentioned as performing the office of conductors between the *nerve-centre* and the parts to which they are distributed. But some fibres convey impressions *towards* the centre, as those of sensation, and others impulses *from* it, as those of motion; the former are called *afferent* fibres, the latter *efferent*. But these nerve-fibres may be also stimulated into action artificially: thus, an electric current transmitted along a motor nerve, or even pinching it, produces contraction of the muscles it supplies, and mechanical irritation of a sensitive nerve causes pain. Use is sometimes made of this knowledge, in stimulating the motor nerves of a paralysed limb by magnetism.

When any part of the body is touched, we know at once the exact spot; and this is probably due, in a measure, to habit and education. At any rate, when a piece of skin is partially raised and turned round, as is sometimes done in surgery, to fill a gap made by injury, a considerable time elapses before the patient identifies its new position; and those who have recently suffered amputation constantly complain of pain in the toes or fingers, which is explained by the irritation of the cut ends of the nerve-fibres that supplied these parts.

Some nerves spring in pairs from the under part of the brain and medulla oblongata, and pass out of the skull; these are called *cerebral* nerves; and, as already remarked, there are thirty-one pairs of *spinal* nerves, which all have double roots, and escape from the spinal canal by the several holes in it and the sacral canal.

EXCITO-MOTOR SYSTEM.—There is another important function, of which the spinal cord is shown, by experiment and observation, to be the especial seat, though it is probably associated also, in a higher degree and more complex way, with the great ganglia of the brain. (See p. 97.) It is that of receiving and taking cognisance of impressions, and of propagating impulses, quite independently of the will or, it may be, even knowledge of the individual.

This system, therefore, implies the presence of a centre of nerve-power, and of afferent and efferent nerves, conveying impressions between such centre and the muscles influenced by it. This *reflex action*, as it is called, may occur without our consciousness, as in the case of the heart and intestines, or of the muscular ring which surrounds the pupil of the eye; or we may be conscious of it, though able to control it only partially or for a short time, as in swallowing and breathing.

It is scarcely necessary to remark that this arrangement exists for most important purposes, many of which are obvious, others obscure. Thus, we breathe unconsciously and during sleep. The explanation of this is, that the presence of a poisonous gas in the lungs gives rise to an impression which is conveyed to the upper part of the spinal cord, and thence an impulse is issued along the nerves supplying the great muscle by which we breathe, and this is thus set in action.

SYMPATHETIC SYSTEM.—The remaining nerve-centres and nerves which together constitute a distinct system, not dependent on, though associated with and influenced by, the cerebro-spinal system, are included under the title of "sympathetic;" a name derived from the formerly-supposed function of these nerves, and now retained for convenience sake.

The essential constituents of this system are similar to those of the cerebro-spinal; but the centres or sources of nerve-power are scattered, instead of being aggregated. These centres are *ganglia*, which are distributed, chiefly, along either side of the neck and spine, and in the head and interior of the chest, abdomen and pelvis. Connected with them are nerve-cords, which communicate, as afferent and efferent conductors, between the ganglia and the organs which are influenced by them.

In enumerating the *functions* of the sympathetic system of nerves, it would be incorrect to say that they do not convey sensation, as parts supplied by them are sensitive; but it is most probable that such sensibility is communicated through filaments of the cerebro-spinal nerves, mingling with them. In other respects, the agency of the sympathetic is, apparently, identical with the reflex action of the cerebro-spinal system, *i.e.*, an impression is originated in an organ, conveyed to the ganglionic nerve-centre, and thence an impulse is reflected to the same organ, or it may be to some other, which produces the required act, whatever it may be; and these acts are either the muscular movement of the organ, without the controlling influence of the will, or some function connected with secretion or nutrition.

Thus it will be perceived that the anatomical division of the nerve-centres is into cerebro-spinal and sympathetic, and that all their physical functions are comprised under the three heads of—

(1) Sensation, common and specific.

(2) Muscular motion.

(3) The various functions associated with the nutrition of the frame.

To these we have to add the instrumentality of the brain, in its relation to the senses and the intellect, in the manifestation of mental phenomena.

The brain is exclusively the seat of sensation and of voluntary power of movement.

Both brain and spinal cord are the centres of reflex actions; and the spinal cord is further a conductor of impressions to, and of impulses from, the brain.

The ganglionic centres are sources of excito-motor or reflex actions; and are specially associated with organic life, and the control of nutrition.

Harmony of action is ensured by the commisural connection between the two sides and the different parts of the brain with each other (see p. 92); and also by the interchange of nervous fibrils between the different systems or nerve-centres.

SLEEP.

Activity entails fatigue and structural waste, which demand repose and renewal of tissue, to recruit the flagging energy, and to supply the material loss.

It has been shown that all—even the organic—functions have their intervals of rest; * and we know that when the tired limbs are stretched at ease, they recover strength. But weariness still attends the exercise of volition; something more is required, for the brain needs rest. The repose of the brain is sleep.

Healthy sleep, then, is a suspension of the active functions of the brain. The senses are dormant; the exercise of volition is in abeyance; and, so far as we know, the other intellectual faculties also rest; at any rate, the will ceases to control the mind.

How is sleep induced, and on what conditions does it immediately depend? We are familiar with the sense of exhaustion which needs this repose, and of the recruited energy which succeeds it; and few of us but have realised the weary restlessness consequent on its denial, or when it is wooed in vain. But this experience affords no answer to the above inquiry.

* See pages 67 and 79.

Formerly, it was taught that the accumulation of blood in the brain induces sleep; but observation seems to prove that such is not the fact, for it has been shown, in cases of accidental injury, and by experiment, that the brain is paler, that it contains less blood in its capillary vessels, during sleep. It may be affirmed, then, that the diminished supply of blood is a condition accompanying sleep; and it has been assumed that this condition of the circulation is the *cause* of sleep, though it has not been satisfactorily demonstrated that it is not simply the concomitant, or possibly the consequence of sleep. Supposing it to be the cause, the question naturally arises, How is the supply of blood controlled? This has been thought to be due to the agency of the sympathetic ganglia which control the muscular walls of the arteries, and in the following way.

By the exercise of this influence the arteries are contracted, and therefore admit less blood; and as the ganglionic power is supposed to become more energetic as the cerebral activity diminishes, so, in a proportionate degree, the arteries contract, till finally the cerebral functions are suspended, *i.e.*, sleep supervenes. Certainly we have reason to believe that mental activity is dependent on the supply of arterial blood, and we know that interruption of the flow of blood through the supplying arteries—the carotids—induces a stupor very much resembling, if not identical with, sleep; whilst the free communication between all the great arteries of the brain secures an equal distribution of the blood, whether of more or less, under ordinary circumstances. Moreover, the paralysing influence of depressing emotions of the mind, as of terror, produces pallor of the face, and exciting emotion flushes the cheek. It has been also observed that, in sleep, when the pupil of the eye is contracted, the nervous expansion, or retina, is paler than natural. These circumstances are adduced as lending colour to this theory of the immediate cause of sleep. We may, at least, conclude that during night the brain renews its wasted substance and energy, which its constant activity through the day demands.

Dreaming.—But sleep is not always sound and healthy; it is often attended by dreaming, more or less vivid, *i.e.*, by dreams which are more or less distinctly recollected after waking. Indeed, the facility with which even clearly-defined dreams elude our efforts to recall them, would seem to suggest that it is possible the mind is never quite inactive; but, on the other hand, it has been supposed that a dream is compressed into the moment of waking. In many instances, no doubt, this is the case, as when a sudden noise determines the character of a dream.

The state of mind which most prominently characterises dreaming is the uncontrolled sway of the imagination, whereby various impressions are associated together, and are believed to have a real existence. Thus, volition is suspended, together with the ability to distinguish between the real and the imaginary. But, under other circumstances, there may be the will to act, without the ability, as in nightmare. Again, the phenomena of dreaming would seem to indicate that some faculties sleep, whilst others are awake.

The strange mixture of the past with the present, the recurrence of scenes and events long forgotten, the unbidden intrusion of features and voices which have long ceased to be seen and heard, must suggest to the dreamer the belief that even his least heeded words and thoughts leave an impression which is indelible, though the constant succession of new objects of attention, by veiling, may seem to efface that impression.

In *Somnambulism* the dream is acted. The sleepwalker is influenced by the impressions which are present in his dream; and as that portion of the brain is awake which connects the will with the ability to control and direct the bodily organs, he gives expression to his conceptions in words and acts.

The senses are either partially or entirely asleep in some instances; the pupil of the eye is dilated and motionless; but in others, obstructions are avoided, conversation pursued, and changes in temperature appreciated, which prove that the sensorium is awake to external impressions conveyed through the senses, and that the power of reasoning consistently, as well as of remembering past events with great accuracy, is possessed by the somnambulist.

The subject of this singular affection usually awakes weary and unrefreshed, but often quite unconscious of having even dreamed.

SECTION X.

THE SENSES.

Sensation implies a bodily change, effected through some agency and perceived by the mind. Unless such perception accompany the physical change, there can be no sensation.

The seat of sensation is in the brain; and the nerves, which communicate between this centre and the various parts of the body supplied with sensation, may be traced, by distinct roots, into the spinal cord and brain.

The attribute of sensation is common to most parts of the body, and is therefore called *common sensation.* But there exists also the power of perception in other ways, viz., by the senses; and this is termed *specific sensation.*

Common sensation is excited by mechanical or chemical irritants; but the appeal to the senses is made through special agencies.

Each nerve of special sense has its particular centre or point of termination in the brain, and one cannot act in the place of another: each can fulfil its own special function alone.

Sensation, whether common or specific, may be partially or completely suspended, either directly, by injury to or pressure on the brain, or indirectly by the paralysing influence of intoxicating agents on the stomach or lungs: all the machinery for producing an impression is complete, except that the brain is incapable of perception.

It is in this latter way that chloroform and other anæsthetics, as they are called, act. The intoxication —for such it is—thereby produced, is transient; but patients often pass through the various stages of exhilaration, and noisy, and even boisterous excitement, in which natural character is displayed, before the period of stupor and insensibility ensues; and sickness, languor, and headache often succeed after sensibility is restored.

Although common sensation is excited usually by external objects, and thence called *objective*, yet there are sensations to which we are subject, which are originated without such external agency, and these are termed *subjective*.

The senses especially afford examples of these subjective sensations, such as singing in the ears, and motes floating before the eyes; but they are also excited in the nerves of common sensation: as in the tingling of the skin called "pins and needles," and allied conditions. These and similar subjective sensations may be dependent on the agency of some remote cause, giving rise to what are termed sympathetic pains; and the mind is capable, by association, of originating or of reviving sensations. Many of these sensations, occurring in nervous or hysterical persons, are supposed to be purely imaginary, whereas they are real and spring from some internal cause, though probably exaggerated by the mental susceptibility of the sufferer, and the habit of indulging it. In functional derangement or organic disease of the brain, or at the approach of death, these subjective sensations in the organs of special sense sometimes assume a startling reality, affecting, under the guidance of the excited imagination or wandering intellect, the character of particular odours or tastes, or of definite sounds and sights. It is thus that the raving of the delirious drunkard is explained; and in this way we may account for the genuine narratives of visions witnessed by the dying; of the outstretched arms of long-departed friends; or of the varied harmony of music, or the monotonous boom of the church-bell: sights and sounds which are, however, no less real in their spiritual relation to the seer, because they are purely subjective in their origin. But we know it is irrational to suppose that the material senses can be affected by, or take cognisance of, that which has no material existence. Spectral illusions, of which there are many remarkable and well-authenticated instances, admit of the same explanation.

From what has been said it may be inferred that there is a close parallel between the nerves of common and specific sensation. Such is indeed the fact; the nerve and the nerve-centre constituting the essential agents in each case. That which we term the organ of sense, the eye or ear for example, is merely subsidiary; a special, and of course the most convenient, arrangement by which impressions may be made on the nerve-centre through the communicating nerve. But it must be remembered that, although all the lenses, &c., of the eye may be perfect in every respect, they are entirely useless if the nerve be destroyed, or the nerve-centre in the brain be incapable of perceiving the transmitted impression.

With these preliminary remarks we may now proceed to consider the structure and functions of the organs of special sense; and first that of the sense of touch.

Touch.—It has been already remarked ("Skin," p. 38), that the entire skin is very sensitive, being largely supplied with nerves; but some parts are more highly endowed than others, and possess the special attribute of distinguishing the characters of different surfaces, and of discriminating delicately the temperature of objects with which they are brought in contact. The utility of this general sensitiveness is obvious, when we consider how important a safeguard this property is to protect the body from threatening danger. Pain, therefore, is a provision for our security against far greater evils than the suffering which is inflicted; for it warns us to avoid that which, by its repetition or continuance, would lead to serious and even permanent and irreparable mischief. We see this frequently exemplified in parts which are paralysed and have lost their sensibility: the peculiar sensitiveness of the eye is an instance; and if we did not suffer pain on plunging the hand into very hot water, or holding it too near the fire, it would be burnt.

The *tactile* sensibility, as it is termed, or the sense of touch, is especially resident in the tips of the fingers and in the tongue, and also in the lips; and this property is, no doubt, greatly improved by use and education, as we witness in the blind to a remarkable degree, for they are compelled to employ the sense of touch for that of sight.

A peculiarity in the texture of the skin exists for the special purpose of giving it this tactile sensibility; and this consists in the presence of numerous little conical elevations of the true-skin, called Papillæ, to which the terminal filaments of the nerves are abundantly supplied: these are best studied in the palm of the hand and fingers, and corresponding parts of the foot, where they are most numerous. Here they are prominent, and arranged in rows along the parallel raised lines, which are separated by furrows, and curved around the tips of the fingers.

Thus, it will be observed that the sense of touch is simply a modification of ordinary or *common* sensation, dependent on the arrangement or disposition of the skin in which the nerve filaments terminate.

TASTE.—In the senses of taste and smell, the nerve-centre in which the respective nerves terminate is endowed with the property of distinguishing flavours and odours. In the case of the tongue and palate, the arrangement is of a nature closely allied to that which has been described as existing in the sense of touch. But the compound office of the tongue, as a tactile organ as well as an organ of taste, and the intimate association which exists between the senses of taste and smell, somewhat complicate the understanding of this subject; and in order to disentangle the web as far as may be, we must consider severally the seat of taste, the nerves on which it is dependent, and the alliance of this sense with the other two mentioned.

As there is an obvious utility in the sense of taste similar to that of touch, in enabling us to distinguish between different sorts of food by their flavour, and thus to select or reject according to circumstances, the position of this organ is at the inlet of nutriment, and constitutes a guard, as it were, against the intrusion of noxious substances, whilst it ministers to the enjoyment of that which is suitable.

But this property is not limited to the tongue; it extends also over the back of the palate and upper part of the pharynx, a circumstance with which the epicure is practically acquainted; as the flavour of a favourite food or drink is not fully estimated until it is swallowed: and here again we at once have exemplified how much influence the sense of smell has in perfecting that of taste, as the delicate flavour of a choice wine is scarcely at all appreciated without the aid of the allied sense.

The *Tongue*, of which the form is familiar, is composed chiefly of the muscles which move it in every direction, covered by a mucous membrane. The structure of this covering is different at various parts; these modifications having a relation to the varied functions of the organ.

An artery, the lingual, derived from the carotid,* or great artery of the neck, supplies the tongue with blood; and two nerves are distributed on its surface, to endow it with common and specific sensation; and a third is appropriated to its muscles.

* See page 99.

In order that the tongue may perform its office efficiently, it is necessary it should be moistened with the healthy secretion of the salivary (p. 50) and mucous glands. When this is deficient or disordered, as in disturbed health, the taste is perverted or absolutely suspended; and a similar consequence accompanies derangement of the mucous membrane of the nose and deteriorated sense of smell, as in common cold. Moreover, it is essential that substances be dissolved in order to their being tasted. But the special sense may be excited also by mechanical irritation or the influence of electricity.

From what has been stated, the alliance between the sense of smell and of taste, and the dependence, in many instances, of the latter on the former, will be understood. In fact, it may be affirmed that the taste of any substance which can be smelt is incomplete without the co-operation of both senses. In like manner, whatever appeals to the sense of touch, such as acrid or pungent substances, is partly dependent on this tactile sensibility for its perception; probably in some instances entirely so.

Most of the more usual morbid conditions of the tongue are due to an altered state of the epithelium, overlying its mucous membrane, and these conditions are valuable as indicating corresponding changes in the mucous membrane of the stomach and alimentary canal. The furred tongue is an example; and again, an unnatural redness of its surface, caused by its being partially denuded of epithelium, indicates irritation of the mucous membrane generally.

Some further remarks on the uses of the tongue will be found under the head of "Respiration" and of the "Voice;" and an enumeration of the various offices of this interesting and versatile organ is given under the latter heading. (p. 85).

Smell.—Before describing the sense of smell, it is necessary to give a little attention to the relation and structure of the parts concerned.

The prominence of the nose constitutes a characteristic feature, peculiar to the human face. In form and size it varies much less in special types of face, as in the Negro or Tartar; but in the mixed races there is great variety in both respects; and this aids materially in giving variety to the expression of the face.

The prominence of the nose is due, in part, to the position of the short nasal bones, which stand out from the centre of the frontal bone; but chiefly to the size of the cartilages which form the expanding sides of this organ.

A central partition, also of cartilage in front, but of bone behind, divides the interior of the nose into two compartments, which are frequently unequal, in consequence of this partition inclining to one side or the other. The interior of the nostrils is protected by short hairs, which obstruct the ingress, during breathing, of dust or other objects floating in the air, and which the mucous secretion helps to wash away.

The back outlet of the nostrils is into the upper part of the pharynx, behind the curtain of the palate. There are several small openings into either nostril, the most important of which is the little duct which conveys the tears from the eye.

The nose is supplied with common sensation; and this is very acute, for the obvious purpose of protection from injury, by the intrusion of any foreign matter. When the membrane is thus irritated a copious discharge of mucus is caused, and the intruding matter is expelled by the spasmodic act of sneezing.

But the sense of smell is due to the presence of a special nerve, the *olfactory* or first pair of cerebral nerves.

It is sometimes difficult, in this organ as in that of taste, to distinguish between sensations which are common and those which are special. The snuff-taker requires both; for he must have his luxury of a nature to be agreeable in odour, as well as capable of tickling the nostrils. Moreover, as already remarked (see

"Taste," p. 105), the senses of taste and smell are often associated in their function.

In order that any object may be smelt, it is of course necessary, as in the case of all the senses, that there should be a material impression; and this can only be when such matter is present in the atmosphere, in the form of infinitely minute particles, or as odorous gas or vapour; and as the sensitive membrane of the nostrils is covered by mucus, these odorous particles or gases must be mixed with or dissolved in it before they can be smelt.

But if the mucous membrane is in an unhealthy state, and there is insufficient or very tenacious mucus secreted, the sense of smell is impaired or suspended for a time. This is exemplified in a common cold. We often assist the sense of smell by drawing the air rapidly and frequently through the nostrils; in short, by sniffing. The pungency, apart from the odour, of some substances, is felt often through the communication with the mouth, as when mustard produces a painful irritation of the nostrils and eyes simultaneously; and occasionally the organ has a painfully retentive sense of disagreeable odours.

The sense of smell is more extended in its range in man; but far more acute, in its adaptation to their respective requirements, in the lower animals. Such adaptation is in special relation to food; and the predaceous animal follows, with unerring certainty, the track of his prey by scent; and the herbivorous feeder selects, with equally unerring sense, his appropriate food.

Hearing.—The conditions which are necessary for hearing are, as in the case of the other senses, a special nerve, a suitable surface for it to be spread out on, and the means of making the required impression. Other arrangements, however, exist for concentrating and defining these impressions; and these constitute an important part of the organ of hearing.

Before proceeding further in the description of the ear, the nature of sound should be understood; though it will be necessary for the reader to consult some treatise on this subject for more than the most elementary information.*

The atmospheric air which surrounds us is the medium by which sound is produced. If a stone be cast into the still surface of a pool of water, a wave is caused, which extends in widening circles from the spot where the stone fell towards the margin of the pool. If the surface of a field of corn be watched, when a light breeze is crossing it, a wave will be observed to pass over it from side to side. Now, in neither of these instances, nor in the waves of the sea, is there any corresponding displacement of the water or corn which is set in motion, but merely a communicated impulse, which passes from one part to another. So it is with the air. An impulse is given to one portion which is communicated to another, and thus a series of waves or undulations, travelling about 1,100 feet per second, is caused, which strike the organ of hearing and impress the special nerve of this sense. If these undulations are short and rapid a high note is produced, if long and slow, a low note is the result; the intermediate notes varying with the rapidity of the undulations. Water and solid bodies are competent to transmit sound in a similar way, viz., by undulations or vibrations communicated through them.

The organ of hearing consists of three divisions, the external, middle, and internal. The first of these is that which we see on the side of the head, and the canal leading from it, into the orifice of which the finger may be passed; the middle compartment is the *drum* or *tympanum;* the inner one is called, from its complexity, the *labyrinth*.

The external ear is called the *auricle*, and the passage leading from it the *auditory canal*, which is lined by a continuation of the skin inwards; it is protected from the intrusion of foreign bodies or of insects, by the obliquity of its direction, by small hairs growing from

* Tyndall's Treatise on "Sound" is admirably adapted for this purpose.

its surface, and by the presence of a bitter brown secretion, called *cerumen* or ear-wax, which is the product of special glands.

The middle ear, or *tympanum*, is a drum-like cavity, separated from the auditory canal by a fibrous membrane which is attached to the bony rim of the passage, and completely shuts in the drum. The skin of the

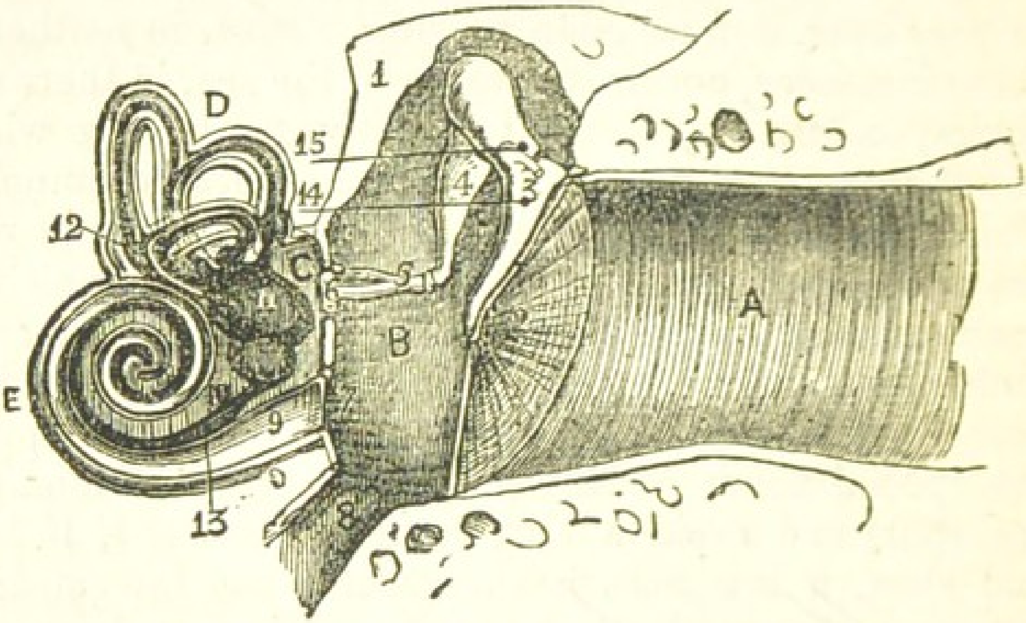


DIAGRAM OF EAR.

A. External auditory passage.
B. Tympanum.
C. Vestibule.
D. Semicircular canals.
E. Cochlea.
1. Roof of tympanum.
2. Membrane of tympanum.
3. Malleus.
4. Incus.
5. Stapes.
6. Base of stapes at oval opening.
7. Round opening between tympanum and cochlea.
8. Eustachian tube.
9. Scale of tympanum.
10. Scale of vestibule.
11. Membranous vestibule.
12. Membranous canals.
13. Membranous scale of cochlea.
14. Line of traction of laxator tympani.
15. Line of traction of tensor tympani muscle.

auditory passage is continued over the outer surface of this membrane.

The interior of the drum communicates with a hollow cellular space in the bony prominence behind the ear; air is contained in these, the *mastoid cells*. But the chief communication, by which air has access to the drum, to support its membrane, is through a canal, called the Eustachian tube, which opens into the throat, just behind the nostrils. A small chain of bones—*ossicles*—crosses the tympanum towards the labyrinth, named *malleus*, *incus*, and *stapes*.

The first somewhat resembles a hammer, the second is named from its supposed resemblance to an anvil, though it is more like a double tooth; and the third is exactly like a stirrup; between the incus and stapes is a small round bone like a grain of sand. The inner bone or stapes fits over an oval opening communicating with the labyrinth. Minute muscles act on these bones: one draws the stapes backwards, and two act on the hammer-bone, whereby the membrane or head of the drum may be made more or less tense; for the malleus is firmly attached to this membrane, and when the former is moved, the latter moves with it.

Thus, the small chain of bones stretches across an air-chamber, being attached at one extremity to the drum membrane, and at the other end fitting over the communication with the labyrinth, where the nerve is distributed. In this way the undulations of the atmosphere are conveyed to the special nerve of hearing; viz., by the vibration of the membrane of the drum, which sets the chain of bones in motion.

It would not answer any good purpose, whilst it would occupy considerable space, to attempt to render intelligible the intricacies of the labyrinth. It is sufficient to say that it consists of several parts, named, respectively, the *vestibule*, *cochlea*, and *semicircular canals*, the particular uses of which are, in a measure, conjectural; though we know that they present an extended surface, whereon the special nerve of hearing is spread out. They are lined by a delicate membrane, and occupied partly by fluid, having suspended in it minute calcareous particles, whereby the transmission of impressions to the nerve is materially assisted. Of these divisions of the labyrinth the vestibule is the central, and communicates with the chain of bones crossing the drum on one side, and with the cochlea and semicircular canals on the other.

Thus, the external ear collects the undulations or vibrations, which the middle ear or tympanum transmits to the inner ear or labyrinth, where sound is produced by the impression these vibrations make on the auditory nerve (p. 111); and these vibrations, as just now remarked, may be conducted, though with diminished intensity, from air through a fluid or solid medium, or in the reverse direction; but the actual conditions existing in the organ of hearing are those best calculated to conduct atmospheric vibrations, viz., a tense membrane in contact with a solid body, represented by the hammer-bone.

But these conditions could not be properly fulfilled unless the cavity crossed by the chain of bones be occupied by air, either as regards the relations of the membrane or the small chain of bones. By the free communication with the throat, through the trumpet-shaped opening of the Eustachian tube (see fig.), the atmospheric pressure is equalised, and the varying tension of the drum membrane is permitted. When this membrane is rendered more tense by the little muscle attached to the hammer-bone, it vibrates less readily, and therefore sound is not so easily transmitted; the converse is the case with regard to the action of the relaxing muscle; but inequality of pressure on either side of the membrane produces partial deafness; thus if the Eustachian tube be obstructed, as in swelling or inflammation of the throat, this result is often observed.

Apart from the general function ascribed to the labyrinth, its various component parts aid in communicating vibrations from the surrounding bones, and in appreciating the modulations of sound. But it would seem that the capability of detecting the direction from which a sound proceeds is acquired—at least in great measure so—unless, indeed, the different direction in the curves of the three semicircular canals may be supposed to be associated with this faculty.

As with the other senses, animals needing a quick sense of hearing possess it in a far more acute degree than man; and this is often aided by an expansion or prolongation of the external ear. But man has a more extended range of capacity to enjoy, if not to appreciate, sounds combined in harmonious music; varying, however, remarkably in different individuals.

SIGHT.—As it is impossible to understand the uses of many parts of the eye without some acquaintance with the properties of light, a few requisite remarks on this subject will first be made. For further information, the reader must consult some work on optics, or the article on light in some encyclopædia.

Although the properties of light are well understood, and the phenomena attending its presence under different circumstances are satisfactorily explained, yet what light is, or how the condition we call light is produced, is not so certainly known.

That which is called the "undulatory theory" is now generally received; it assumes the presence of an imponderable ether pervading space, and that the undulation or vibration of this ether causes light; very much in the same way as the waves in the atmosphere produce sound.

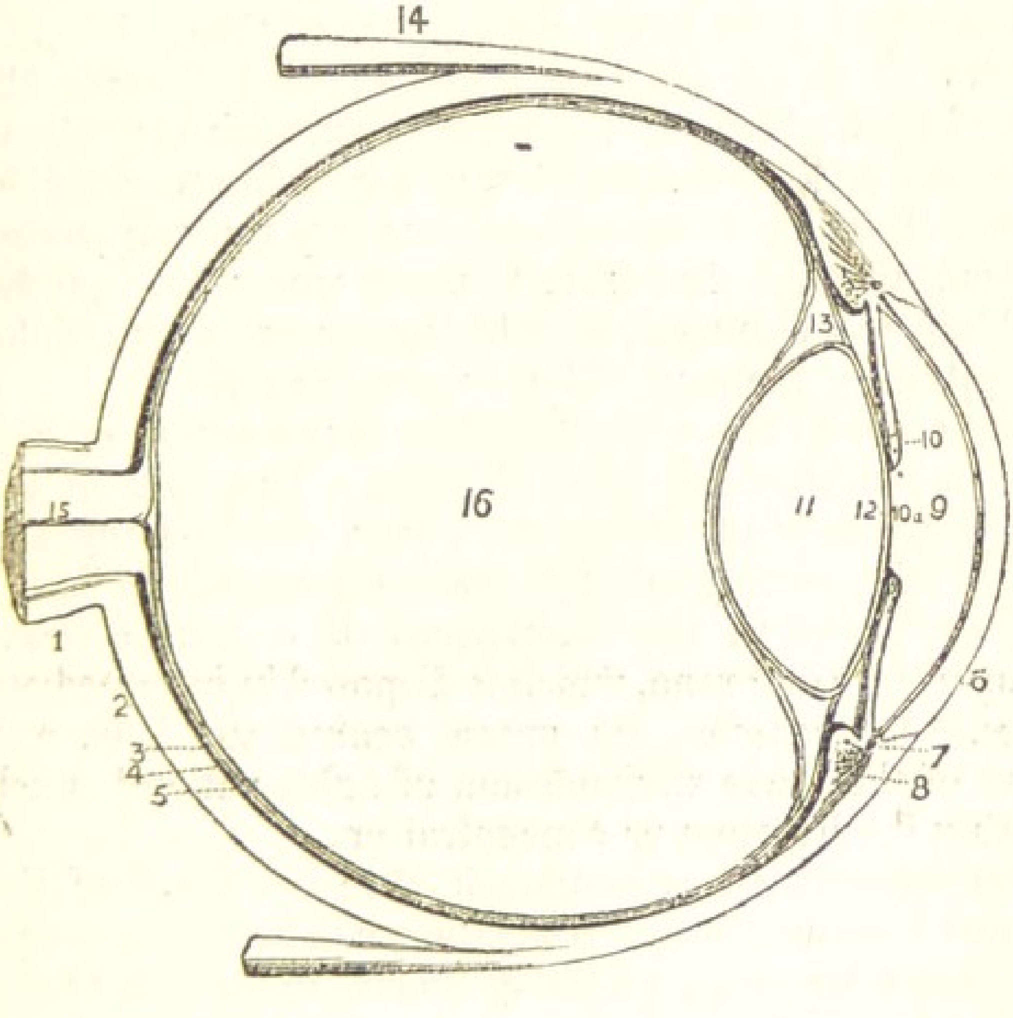
Light is said to consist of rays, which proceed from a self-luminous body in a straight line. When rays of light meet with any object in their progress, (1) some of them are either reflected, *i.e.*, sent back, or (2) they are transmitted, or (3) they are absorbed and lost. The first condition occurs when the surface of the body is of polished brightness, as silver; the second, when the body is transparent, as glass; the third, when the body is dark, opaque and dull.

But when rays of light, in passing through a denser transparent medium than the atmosphere, fall upon the surface of such medium obliquely, they are bent, or refracted, as it is termed technically. Now, a solid transparent body, which is rounded in form like the outside of a watch-glass, in other words convex, also refracts the rays of light; and being bent towards the centre, they are there collected into a point or focus. The reverse of this takes place where the surface on which the rays fall is hollow or concave, *i.e.*, they are bent outwards or dispersed. Moreover, a double convex lens not only causes the rays to converge when they enter it from a rarer medium, but also when they leave it to pass again into one less dense.

The *orbit*, in which the eye is lodged, is a conical cavity, its apex presenting the hole for the optic nerve to enter. It is constituted by several bones, but especially by the frontal bone above, the upper jaw below, the cheek-bone on the outer side, and the thin ethmoid on the inner side (p. 29). Its rim is prominent, thick, and very hard, to adapt it to resist external violence; the eye is further protected by the prominence of the nose. In health, a considerable quantity of fat forms a soft cushion on which the eye rests; the absorption of this fat, in sickness, gives the hollow-eyed appearance which results from the partial loss of this cushion.

The *globe* of the eye, or eyeball, is in the form of a sphere, and the bulk of it consists of transparent humours, which are enclosed in membranes spread around them. The strongest of these membranes or coats is thick and fibrous, and constitutes the white, opaque portion of the globe seen behind the dark centre; it is called the *sclerotic* coat, and has, continuous with it, and resembling a watch-glass, the transparent *cornea* in front. The cornea is also fibrous in texture; but the arrangement of its component parts is such as to permit the free transmission of the rays of light. The various muscles, moving the eye in different directions, are inserted into the sclerotic near to the cornea.

The *conjunctiva*, a delicate secreting membrane, lines the lids and covers the sclerotic; it is turned back or reflected from the lids, so that nothing can pass behind it. The lids themselves are supported by cartilage plates, of which the upper is the deeper; and their edges are supplied with little follicular glands, to keep them moist (p. 43). A small delicate canal passes from each eyelid to a duct, which leads into the nose, and through which the ordinary secretion of tears is conveyed into the nostrils. The upper eyelid is raised by a special muscle; and an annular or orbicular muscle surrounds both the lids, which closes the eye. The ducts of the tear-gland open on the surface of the conjunctiva; and the little red fold of this membrane at the inner corner of the eye prevents the accumulation of particles of dust, and directs them on to the cheek.



SECTION OF GLOBE OF EYE.

1. Optic nerve divided.
2. Sclerotic coat.
3. Choroid.
4. Retina.
5. Hyaloid membrane.
6. Cornea. Canal, at junction of cornea and sclerotic.
8. Ciliary muscle, consisting of circular and radiating fibres.
9. Anterior chamber.
10. Iris.
10a. Pupil.
11. Lens.
12. Capsule of Lens.
13. Canal of Petit, between divisions of suspensory ligament.
14. Superior straight muscle of globe, divided.
15. Central artery of retina.
16. Vitreous humour.

On the inner or concave surface of the sclerotic coat, a very vascular membrane—the *choroid*—is spread out, which is covered with pigment cells and black pigment; and this has a fringed circumference of what are called *ciliary processes*.* Again, within the choroid is the transparent nervous expansion called the *retina*, consisting of both nerve corpuscles and of nerve fibres, freely supplied with blood.

The conjunctiva is moistened by the tears derived from a gland which lies over the outer side of the globe, and thus the movements of the eyelids and eye are facilitated, and the clearness of the cornea is preserved. The sclerotic gives form and support to the globe, and attachment to its muscles. The choroid absorbs the rays of light which are transmitted through the retina; whilst the last-mentioned nervous expansion receives the images of external objects and conveys the impression of them, through the nerve, to the brain. But in order to obtain these images, suitable lenses are required for concentrating the rays of light upon the retina.

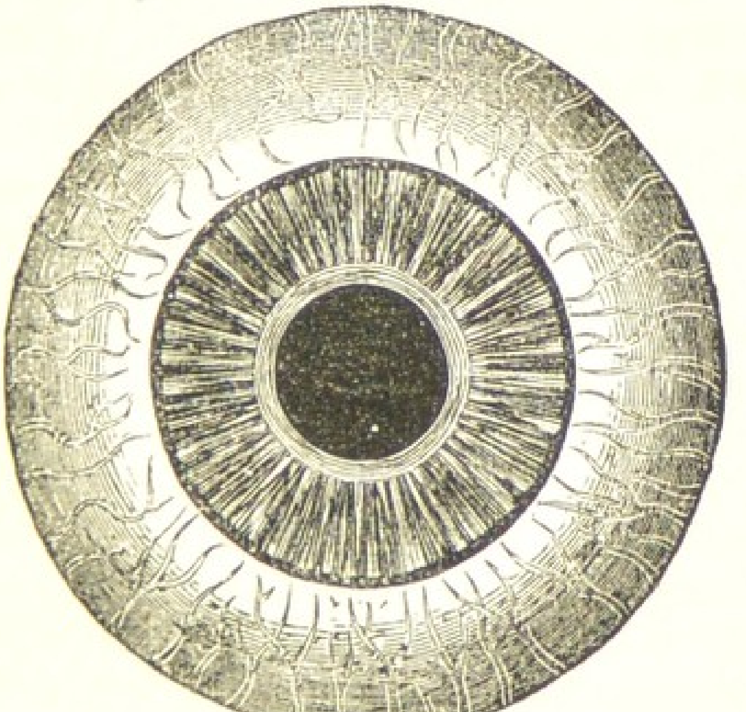
The cornea has partly the office of refracting as well as of transmitting the rays of light. The bulk of the globe consists of the *vitreous humour*, which is soft and jelly-like in consistence, but really composed of a limpid fluid contained in the interspaces of a very delicate transparent membrane, which is disposed in intermediate layers. It occupies the space behind the lens, and allows of the ready transmission of light, without much affecting its direction or concentration.

The *crystalline lens* is imbedded in the front of the vitreous humour, in which position it is held by a strong and elastic ligament, which connects its margin to the ciliary processes of the choroid coat. It is perfectly

* This pigment is sometimes absent, and its importance is proved by the painfully dazzling effect of a bright light on those who have the defect; they are called albinos. This imperfection exists sometimes in white rabbits and other animals. The inner surface of the choroid presents, in some animals, a brilliant iridescent appearance, as in the cat family: this metallic lustre is due to a partial absence of the pigment, and assists the sight when the light is feeble.

transparent and convex on both sides, like an ordinary magnifying glass, but more prominent behind than in front. It is arranged in several layers in a complex way, and becomes more dense as the centre is approached. Its structure and the arrangement of its component parts render it very elastic; and its convexity diminishes, whilst its hardness increases, as age advances.

Between the lens and the cornea there is a considerable space, occupied by a transparent fluid, containing a small quantity of common salt in solution, and called the *aqueous humour*. By the presence of this fluid the cornea is kept uniformly convex; but it also answers another very important purpose, that of allowing the perforated curtain within the eye to float and move at freedom.



THE HUMAN EYE.
Showing the arrangement of the fibres of the iris.

This perforated curtain is called the *iris*, and the central aperture in it is named the *pupil*. The iris is a muscular structure, acting independently of the will, and varying in colour from a light grey to a deep brown or nearly black; it is covered behind with a dark pigment to prevent light from passing through it. The circumference of the iris is firmly attached to the line of junction between the cornea and sclerotic; and from this circular line involuntary muscular fibres, the ciliary muscle, extend backwards on the outer surface of the ciliary processes and border of the choroid coat, to which they are connected, and which it is their business to pull forwards when required so to do. The free border of the iris floats in the aqueous humour, and divides the space between the cornea and lens into two *chambers*, which communicate, of course, freely through the central aperture or pupil; but, as the curtain is much nearer to the lens than to the cornea, the anterior chamber is the larger. The muscular fibres of the iris are both radiating and circular, the latter forming the margin which surrounds the pupillary aperture, and the former composing the circumference of the curtain. By their contraction, respectively, the pupil is contracted or dilated (see fig. p. 117).

With the few remarks already made respecting the properties of light, and the foregoing brief description of the eye, the reader will be prepared to understand what has now to be said regarding the mode in which the impression we call vision is conveyed to the brain. As in the other senses, the nerve-centre is the organ of perception; and all the beautiful arrangement of lenses of different consistence, of muscular curtain, of pigment and of tears, is merely subservient to the purpose of ensuring a ready transmission of light, and a true picture of external objects on the expanded nerve, the retina.

The succeeding remarks will have reference especially to

(1) The concentration of the rays of light;
(2) The regulation of their admission to the retina;
(3) The adaptation of the eye to distance;
(4) The way in which the nerve and brain are impressed with the size, form, and movement of bodies;

(5) And the subjective delusions to which the organ is liable.

If the rays of light were admitted directly to the retina, they would pass in parallel lines and produce the simple impression of light. Therefore it is necessary that the rays proceeding from any object should be concentrated by being bent or refracted. This is effected to a certain extent by the cornea, the aqueous humour, and the vitreous humour; but far more importantly so by the crystalline lens, the refracting power of which increases, with the increasing density of the lens itself, towards its centre. It is, of course, an essential condition that the retina, which is concave towards the lens, should be placed at a proper focal distance for the image to be perfect; and this is the case in the perfect eye; but the bending of the rays of light is such, that those which proceed from the upper part of an object are concentrated on the lower part of the retina, and *vice versâ*. The varying density of the humours, through which the rays of light pass, correct the tendency which would exist to the decomposition of the white ray into its coloured elements, if there were only one lens.

But too much light may be admitted to the retina; and even that which is necessarily transmitted to it would produce a confused impression if it were reflected; therefore, there exists an arrangement by which the quantity of light may be restricted as required, and also whereby the superfluous rays, and those which were necessary for sight, may be absorbed and got rid of. The iris performs the former office, the black pigment of the choroid coat and of the iris the latter.

The iris acts under the excito-motor nerve influence, the retina being the afferent nerve, and the delicate fibrils supplying the iris itself the efferent nerve (p. 96). Thus, a strong impression of light produces, by this reflex action, contraction of the iris, and diminution of the pupillary aperture; the reverse is the case when light is deficient; the pupil is then dilated.

As the passage of the rays of light is limited to the pupillary aperture in the iris, by this curtain being darkened with black pigment, the only rays that can create confusion are those which, having performed their office of impressing the retina—a transparent membrane during life—might be reflected. This risk is obviated by the choroid, with its pigment, which is spread out over the whole outer surface of this expansion of the nerve (p. 116).

How is the eye adapted to distance? by what power do we unconsciously regulate the focal property of the lenses, so that we can see distant objects distinctly, as well as near objects? This subject has been much discussed; but there seems now to be little reason to doubt that it is dependent on the varying convexity of the crystalline lens, which is determined by the pressure to which it is subjected. In viewing near objects the front of the lens becomes more convex, and the pupil is contracted, and the reverse is the case in looking at distant objects. Now, it will be remembered that the lens is surrounded by a strong elastic ligament, and is itself elastic; also that the ciliary muscle is attached to the same ring which corresponds to the connection between the circumference of the iris and that of the lens, and that of the cornea to the sclerotic. Supposing this elastic ligament to be usually compressing the lens in its circumference, so as to render it more flat than it would otherwise be, the ciliary muscle, by its action on the ciliary processes and elastic ligament, would relax the latter, and thus permit the lens to become more convex. Such, at least, is the explanation of this power of adaptation now generally accepted.

Some persons are deficient in this power of adaptation, as in short and long-sighted persons. Usually the former class suffer in consequence of an undue convexity of the lens, or prominence of the cornea, for which concave glasses are required. In advancing age the shrinking and flattening of the lens demand convex glasses, which increase the magnifying power of the eye.

A curious circumstance, worthy of note, is that one spot on the retina is entirely insensible to light; and this is at the point of entrance of the optic nerve.

The following experiment will prove this fact. Close the left eye, and fix the right on the dark spot, whilst the book is held up three or four inches from the face.

Then move the book slowly farther away, keeping the right eye steadily fixed, and suddenly the cross will disappear; but on removing the book still farther it will presently come into view again.

It has been remarked that the rays, which enter the lens at its upper part, come to a focus at the lower part of the retina, and *vice versâ*. The consequence is that the image of the object is inverted. There has been much speculation as to the manner in which this inversion is corrected; how it is that we receive an impression on the mind the reverse of that which is made on the retina. No satisfactory conclusion has been reached; but it seems probable that the correction is a mental act, of which we are unconscious. There can be little doubt that the size and distance of objects are learned very much by observation and experience; for we often see the infant striving to seize objects entirely beyond its reach; but the relation of objects to each other is correctly appreciated, by the impression being made on different points of the retina in corresponding relation to the objects themselves. In the same way bodies are observed to change their position, to move, by different parts of the retina being successively impressed, or by the conscious act of following the moving object with the eye.

Our appreciation of form in outline is due to the same cause, viz., the correspondence of the image on the retina; but the more complex perception of a solid body is acquired, or, at any rate, perfected, by education. No doubt the outline of a cube, for example, is seen differently by each eye, and the combination of the two impressions is correctly interpreted after the eye has been educated. Each compartment of a stereoscopic picture represents what either eye would see separately; the real object, so to speak, is decomposed in each picture, and recomposed when both are seen together through the stereoscope; it is thus the impression of solidity is produced by the use of this beautiful instrument.

The power we possess of moulding two images—one on either eye—into a single perception has been variously explained; and the partial crossing of the fibres of the optic nerves has been supposed to be associated with this faculty. It would seem, however, sufficient explanation to suppose that the visual impressions are identified in the nerve-centre, and that the act is in great measure mental. Though we hear with each ear separately, the sound is not doubled when both ears are impressed. When, however, *different* parts of each retina receive a *similar* impression at the same time, as in squinting, then the vision is doubled.

An impression made on the retina remains for an appreciable time, after the object making the impression is removed. This is continually exemplified in the movements of common objects, such as the rapid revolution of a carriage wheel, or by whirling a burning stick in a circle; many tops are constructed to illustrate this fact. But even the long duration of these impressions is insufficient to produce a mental perception unless the attention is engaged, and the impression may be indistinct in consequence of the lack of adaptation to distance.

The subjective sensations of the eye are sometimes very remarkable, and these illusions are usually associated with functional disorder or disease of the brain. They may be transient, or may last for a considerable time, giving rise to the conviction that visions have been witnessed, or that the subject of them is haunted by some supernatural visitor. The well-authenticated narratives of these cases are numerous, and very curious and interesting, but would occupy too much space to be introduced into these pages.* The delirious drunkard is often the subject of these strange optical delusions; and so, likewise, is the opium-eater.

The various arrangements which exist for adapting to each other the senses and the agencies by which they are respectively impressed, is a deeply interesting subject of contemplation. What we term sight, hearing, smell, taste, and touch have no abstract existence. All the conditions necessary, on the part of the agents, for producing these impressions might be present, yet without any result, if there were no special nerves to appreciate them; and the modifying apparatus is, in each instance, scarcely less essential to the function of the sense with which it is allied. It is true that light has other offices than that of impressing the sentient extremity of the optic nerve; that vibrations of the atmosphere are the necessary consequence of its concussion; that plants diffuse through the air the particles which convey their special odours; but there would be neither sight, nor hearing, nor smell, unless the special organs were created to interpret these conditions as light, and sound, and odour.

CONCLUSION.

Life in man, in its full activity, may be regarded as threefold: organic, animal, and intellectual; and the offices of the latter two may be suspended without life ceasing; *i.e.*, insensibility to all external impressions,

* The reader may consult, as accessible books, Brewster's "Natural Magic," Abercrombie on the "Intellectual Faculties," and the "English Opium Eater," and Sir Walter Scott's "Demonology and Witchcraft."

and incapacity to exercise the will or to evince any sign of mental activity, are compatible with protraction of life and even a return to health. But the suspension of the functions of organic life is death.

Health implies the performance of all the functions of the body without disturbance.

When this harmonious activity is interrupted, the existence of either functional derangement or of organic change is indicated.

The sources of such disturbance, constituting *disease*, are numerous. They may be conveyed to us from without, or may exist in a latent or inherited form within the body; they may spring from excess, or they may be accidental violence. It is well we should realise the truth, that the phenomena which are usually regarded as constituting disease, are really expressive of the efforts nature is making to afford relief and effect a cure; and it is rather by watching, regulating and assisting these efforts, than by ignoring and opposing them, that disease is treated scientifically and successfully.

The remarks which have been made, from time to time, in the preceding pages, are designed to impress on the reader how much he has within his own power, as regards health, viz., by *moderation* in eating and drinking; by the avoidance of unnecessary stimulus and of indigestible articles of diet; by regulated activity of mind and body, not overtaxing the brain or muscles at one time, and at another leaving them in wasting indolence; by breathing a pure atmosphere; and by preserving as far as possible a uniform temperature, so as not to squander the vital energy consumed in the production of heat, nor to risk the disturbance consequent on sudden vicissitudes, which are so often productive of serious functional derangement, leading to organic disease.

An intelligent comprehension of these familiar truths ought to induce a more hearty acceptance of them, because their value is more clearly appreciated.

Repose is a universal requirement, whether it be in that mimic death which "steeps the senses in forgetfulness," and thus recruits the energy of the nerve-centres, or in the periodic intermissions in the activity of organs which cannot longer rest.

During sleep these functions are subdued; the circulation is less energetic and respiration is slower and more gentle; but these essential offices are not performed without regulated repose. Each beat of the heart is followed by an equivalent interval of rest, and so it is likewise with respiration; the ordinary expulsion of the air is unattended by muscular effort, and that is succeeded by a period of rest. Even the organs of assimilation are permitted to relax; indeed, such remission of their labours is essential to their continued well-being.

Life may be cut short by accident or disease; but if not so, the gradual deterioration of organic structure, consequent on advancing age, produces functional inactivity; until finally one or other organ gives way from its own inherent and increasing susceptibility to derangement, or from some accidental exciting cause; and so the flickering lamp is extinguished.

Death, therefore, is a negative expression, signifying the arrest of functional activity in organs on which the continuance of life depends. These are, most directly, the heart and lungs. When the brain fails to receive its wonted supply of oxygenated blood, in consequence of the faltering action of these organs, it becomes dull to all impressions, and thus death is not the painful transition which its accompaniments, in some instances, suggest to the anxious watcher that it is; but in others the expression of distress occasioned by pain is exchanged for one of calmness, indicative of the cessation of physical suffering before life ebbs away. In each case alike the settled character of the features, after the last breath is drawn, is that of repose. The varied expression denoting the prevalence of some ruling emotion, and abiding in death, exists only in the imagination of the poet or the painter; but the depth of the repose, when the closed eye disguises the truth that the spirit has been "hurled from her throne of light," may impart a softened beauty to the features, to which they were strangers whilst under the sway of exciting and debasing passions.

Molecular death is ever going on whilst life lasts, nay, it is an essential condition, as already pointed out (p. 13), of health and of the repair of textural waste; but *organic* death is necessarily followed by universal molecular disintegration. It is marked by the cessation of all vital phenomena, including the loss of heat and of muscular irritability; the limbs become rigid, the skin ceases to be elastic, and chemical changes ensue; for the laws which govern the inorganic world resume their sway and reign supreme. And thus the elements which once formed the living, moving man, the tabernacle of the intelligent and impassioned spirit, are set at liberty, to enter into new combinations, and so fulfil their ever-active, ever-changing destiny.

THE END.

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