THE BRIDGEWATER TREATISES

ON THE POWER, WISDOM, AND GOODNESS OF GOD,

AS MANIFESTED IN THE CREATION.

TREATISE V.

ANIMAL AND VEGETABLE PHYSIOLOGY CONSIDERED WITH REFERENCE TO NATURAL THEOLOGY

BY PETER MARK ROGET, M. D.

SEC. R. S. ETC.

IN TWO VOLUMES.

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"And there are diversities of operations, but it is the same God which worketh all in all."

1 Cor. xii. 6.

ANIMAL

AND

VEGETABLE

PHYSIOLOGY,

CONSIDERED WITH REFERENCE

TO

NATURAL THEOLOGY.

BY

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ANIMAL AND VEGETABLE

PHYSIOLOGY.

PART II.

THE VITAL FUNCTIONS.

CHAPTER I.

OBJECTS OF NUTRITION.

THE mechanical structure and properties of the organized fabric, which have occupied our attention in the preceding volume, are necessary for the maintenance of life, and the exercise of the vital powers. But, however artificially that fabric may have been constructed, and however admirable the skill and the foresight which have been displayed in ensuring the safety of its elaborate mechanism, and in preserving the harmony of its complicated movements, it yet of necessity contains within itself the elements of its own dissolution. The animal machine, in common with every other mechanical contrivance, is subject to wear and deteriorate by constant use. Not only in the greater movements of the limbs, but also in the more delicate actions of the internal organs, we may trace the operation of many causes inevitably leading to their ultimate destruction. Continued friction must necessarily occasion a loss of substance in the harder parts of the frame, and evaporation is constantly tending to exhaust the fluids. The repeated actions of the muscles induce certain changes in these organs, both in their mechanical properties and chemical composition, which impair their powers of contraction, and which, if suffered to continue, would, in no long time, render them incapable of exercising their proper functions; and the same observation applies also to the nerves, and to all the other systems of organs. Provision must accordingly be made for remedying these constant causes of decay by the supply of those peculiar materials which the organs require for recruiting their declining energies.

It is obvious that the development of the organs, and general growth of the body, must imply the continual addition of new particles from foreign sources. Organic increase consists not in the mere expansion of a texture previously condensed, and the filling up of its interstices by inorganic matter; but the new materials that are added must, for this purpose, be incorporated with those which previously existed, and become identified with the living substance. Thus, we often find structures forming in the bodies of animals of a nature totally different from that of the part from which they arise.

In addition to these demands, a store of materials is also wanted for the reparation of occasional injuries, to which, in the course of its long career, the body is unavoidably exposed. Like a ship fitted out for a long voyage, and fortified against the various dangers of tempests, of icebergs, and of shoals, the animal system, when launched into existence, should be provided with a store of such materials as may be wanted for the repair of accidental losses, and should also contain within itself the latent source of those energies, which may be called into action when demanded by the exigencies of the occasion.

Any one of the circumstances above enumerated would of itself be sufficient to establish the necessity of supplies of nourishment for the maintenance of life. But there are other considerations, equally important in a physiological point of view, and derived from the essential nature of organization, which also produce a continual demand for these supplies; and these I shall now endeavour briefly to explain.

Constant and progressive change appears to be one of the leading characteristics of life; and the materials which are to be endowed with vitality must therefore be selected and arranged with a view to their continual modification, corresponding to these ever varying changes of condition. The artificer, whose aim is to construct a machine for permanent use, and to secure it as much as possible from the deterioration arising from friction or other causes of injury, would, of course, make choice for that purpose of the most hard and durable materials, such as the metals, or the denser stones. In constructing a watch for instance, he would form the wheels of brass, the spring and the barrel-chain of steel; and for the pivot, where the motion is to be incessant, he would employ the hardest of all materials,—the diamond. Such a machine, once finished, being exempt from almost every natural cause of decay, might remain for an indefinite period in the same state. Far different are the objects which must be had in view in the formation of organized structures. In order that these may be qualified for exercising the functions of life, they must be capable of continual alterations, displacements, and adjustments, varying perpetually, both in kind and in degree, according to the progressive stages of their internal development, and to the different circumstances which may arise in their external condition. The materials which nature has employed in their construction, are, therefore, neither the elementary bodies, nor even their simpler and more permanent combinations; but such of their compounds as are of a more plastic quality, and which allow of a variable proportion of ingredients, and of great diversities in the modes of their combination. So great is the complexity of these arrangements, that although chemistry is fully competent to the analysis of organized substances into their ultimate elements, no human art is adequate to effect their reunion in the same state as that in which they had existed in those substances; for it was by the refined operations of vitality, the only power which could produce this adjustment, that they have been brought into that condition.

We may take as an example one of the simplest of organic products, namely, *Sugar;* a substance which has been analyzed with the greatest accuracy by modern chemists: yet to reproduce this sugar, by the artificial combination of its simple elements, is a problem which has hitherto baffled all the efforts of philosophy. Chemistry, notwithstanding the proud rank it justly holds among the physical sciences, and the noble discoveries with which it has enriched the arts; notwithstanding it has unveiled to us many of the secret operations of nature, and placed in our hands some of her most powerful instruments for acting upon matter; and notwithstanding it is armed with full powers to destroy, cannot, in any one organic product, rejoin that which has been once dissevered. Through the medium of chemistry we are enabled, perhaps, to form some estimate of the value of what we find executed by other agencies; but the imitation of the model, even in the smallest part, is far beyond our power. No means which the laboratory can supply, no process, which the most inventive chemist can devise, have ever yet approached those delicate and refined operations which nature silently conducts in the organized texture of living plants and animals.

The elements of organic substances are not very numerous: the principal of them being oxygen, carbon, hydrogen, nitrogen, sulphur, and phosphorus, together with a few of the alkaline, earthy, and metallic bases. These substances are variously united, so as to form certain specific compounds, which, although they are susceptible, in different instances, of endless modifications, yet possess such a general character of uniformity, as to allow of their being arranged in certain classes; the most characteristic substance in each class constituting what is called a *proximate orga-*

nic principle. Thus, in the vegetable kingdom we have *Lignin, Tannin, Mucilage, Oil, Sugar, Fecula,* &c. The animal kingdom, in like manner, furnishes *Gelatin, Albumen, Fibrin, Mucus, Entomoline, Elearin, Stearin,* and many others.

The chemical constitution of these organic products, formed, as they are, of but few primary elements, is strikingly contrasted with that of the bodies belonging to the mineral kingdom. The catalogue of elementary, or simple bodies, existing in nature, is, indeed, more extensive than the list of those which enter into the composition of animal or vegetable substances. But in the mineral world they occur in simpler combinations, resolvable, for the most part, into a few definite ingredients, which rarely comprise more than two or three elements. In organized products, on the other hand, although the total number of existing elements may be smaller, yet the mode of combination in each separate compound is infinitely more complex, and presents incalculable diversity. Simple binary compounds are rarely ever met with; but, in place of these, we find three, four, five, or even a greater number of constituent elements existing in very complicated states of union.

This peculiar mode of combination gives rise to a remarkable condition, which attaches to the chemical properties of organic compounds. The attractive forces, by which their several ingredients are held together, being very numerous, require to be much more nicely balanced, in order to retain them in combination. Slight causes are sufficient to disturb, or even overset, this equipoise of affinities, and often produce rapid changes of form, or even complete decomposition. The principles, thus retained in a kind of forced union, have a constant tendency to react upon one another and to produce, from slight variations of circumstances, a totally new order of combinations. Thus, a degree of heat, which would occasion no change in most mineral substances, will at once effect the complete disunion of the elements of an animal or vegetable body. Organic substances are, in like manner, unable to resist the slower, but equally destructive agency of water and atmospheric air; and they are also liable to various spontaneous changes, such as those constituting fermentation and putrefaction, which occur when their vitality is extinct, and when they are consequently abandoned to the uncontrolled operation of their natural chemical affinities. This tendency to decomposition may, indeed, be regarded as inherent in all organized substances, and as requiring for its counteraction, in the living system, that perpetual renovation of materials which is supplied by the powers of nutrition.

It would appear that, during the continuance of life, the progress of decay is arrested at its very commencement; and that the particles, which first undergo changes unfitting them for the exercise of their functions, and which, if suffered to remain, would accelerate the destruction of the adjoining parts, are immediately removed, and their place supplied by particles which have been modified for that purpose, and which, when they afterwards lose these salutary properties, are, in their turn, discarded and replaced by others. Hence, the continued interchange and renewal of particles which take place in the more active organs of the system, especially in the higher classes of animals. In the fabric of those animals which possess an extensive system of circulating and absorbing vessels, the changes which are effected are so considerable and so rapid, that even in the densest textures, such as the bones, scarcely any portion of the substance which originally composed them is permanently retained in their structure. To so great an extent is this renovation of materials carried on in the human system, that doubts may very reasonably be entertained as to the identity of any portion of the body after the lapse of a certain time. The period assigned by the ancients for this entire change of the substance of the body, was seven or eight years: but modern inquiries, which show us the rapid reparation that takes place in injured parts, and the quick renewal of the bones themselves, tend to prove that even a shorter time than this is adequate to the complete renovation of every portion of the living fabric.*

Imperfect as is our knowledge of organic chemistry, we see enough to convince us that a series of the most refined and artificial operations is required, in order to bring about the complicated and elaborate arrangements of elements which constitute both animal and vegetable products. Thus, in the very outset of this, as of every other inquiry in Physiology, we meet with evidences of profound intention and consummate art, infinitely surpassing not only the power and resources, but even the imagination of man.

Much as the elaborate and harmonious mechanism of an animal body is fitted to excite our admiration, there can be no doubt that a more extended knowledge of that series of subtle processes, consisting of chemical combinations and decompositions which are continually going on in the organic laboratory of living beings, would reveal still greater wonders, and would fill us with a more fervent admiration of the infinite art and prescience which are even now manifested to us in every department both of the vegetable and animal economy.

The processes by which all these important purposes are fulfilled, comprise a distinct class of functions, the final object of which may be termed *Nutrition*, that is, the reparation of the waste of the substance of the organs, their maintenance in the state fitting them for the exercise of their respective offices, and the application of properly prepared materials to their development and growth.

The functions subservient to nutrition may be distinguished according as the processes they comprise relate to seven principal periods in the natural order of their succession. The first series of processes has for its objects the reception of the materials from without, and their preparation and gradual conversion into proper nutriment, that is, into matter having the same chemical properties with the substance

* See the article "AGE" in the Cyclopædia of Practical Medicine, where I have enlarged upon this subject.

of the organs with which it is to be incorporated; and their purpose being to assimilate the food as much as possible to the nature of the organic body it is to nourish, all these functions have been included under the term *Assimilation.*

The second series of vital functions comprises those which are designed to convey the nutritive fluids, thus elaborated, to all the organs that are to be nourished by them. In the more developed systems of organization this purpose is accomplished by means of canals, called *vessels,* through which the nutritive fluids move in a kind of circuit; in this case the function is denominated the *Circulation.*

It is not enough that the nutritive juices are assimilated; another chemical process is still required to perfect their animalization, and to retain them in their proper chemical condition for the purposes of the system. This third object is accomplished by the function of *Respiration.*

Fourthly, several chemical products, which are wanted in different parts of the economy, are required to be formed by a peculiar set of organs, of which the intimate structure eludes observation; although we may perceive that in many instances among the higher orders of beings, a special apparatus of vessels, sometimes spread over the surface of a membrane, at other times collected into distinct masses, is provided for that purpose. These specific organs are termed *glands,* and the office performed by them, as well as by the simpler forms of structure above mentioned, is termed *Secretion.*

Fifthly, similar processes of secretion are also employed to carry off from the blood such animal products as may have been formed or introduced into it, and may possess or have acquired noxious properties. The elimination of these materials, which is the office of the *excretories,* constitutes the function of *Excretion.*

Sixthly, changes may take place in various parts of the body, both solid and fluid, rendering them unfit to remain in their present situation, and measures are taken for the removal of these useless or noxious materials, by transferring them to the general mass of circulating blood, so as either to be again usefully employed, or altogether discarded by excretion from the system. This object is accomplished by a peculiar set of vessels; and the function they perform is termed *Absorption.*

Lastly, the conversion of the fluid nutriment into the solids of the body, and its immediate application to the purposes of the development of the organs, of their preservation in the state of health and activity, and of the repair of such injuries as they may chance to sustain, as far as the powers of the system are adequate to such reparation, are the objects of a seventh set of functions, more especially comprised under the title of *Nutrition*, which closes this long series of chemical changes, and this intricate but harmonious system of operations.

Although the order in which the constituent elements of organized products are arranged, and the mode in which they are combined, are entirely unknown to us, we can nevertheless perceive that in following them successively from the simplest vegetables to the higher orders of the animal kingdom, they acquire continually increasing degrees of complexity, corresponding, in some measure, to the greater refinement and complication of the structures by which they have been elaborated, and of the bodies to which they are ultimately assimilated. Thus, plants derive their nourishment from the crude and simple materials which they absorb from the earth, the waters, and the air that surround them; materials which consist almost wholly of water, with a small proportion of carbonic acid, and a few saline ingredients, of which that water is the vehicle. But these, after having been converted by the powers of vegetable assimilation, into the substance of the plant, acquire the characteristic properties of organized products, though they are still the simplest of that class. In this state, and when the fabric they had composed is destroyed, and they are scattered over the soil, they are fitted to become more highly nutritive to other plants, which absorb them, and with more facility adapt them to the purposes of their own systems. Here they receive a still higher degree of elaboration; and thus the same materials may pass through several successive series of modifications, till they become the food of animals, and are then made to undergo still farther changes. New elements, and in particular nitrogen, is added to the oxygen, hydrogen and carbon, which are the chief constituents of vegetable substances:* and new properties are acquired, from the varied combinations into which their elements are made to enter by the more energetic powers of assimilation appertaining to the animal system. The products which result are still more removed from their original state of inorganic matter: and in this condition they serve as the appropriate food of carnivorous animals, which generally hold a higher rank in the scale of organization, than those that subsist only on vegetables.

Thus has each created being been formed with reference, not merely to its own welfare, but also to that of multitudes of others which are dependent on it for their support, their preservation,—nay, even for their existence. In contemplating this mutual relationship, this successive subordination of the different races to one another, and this continual tendency to increased refinement, we cannot shut our eyes to the magnificent unfolding of the great scheme of nature for the progressive attainment of higher objects; until, in the perfect system, and exalted endowments of man, we behold the last result which has been manifested to us of creative power.

* Nitrogen, however, frequently enters into the composition of vegetables; though, in general, in a much smaller proportion than into the substance of animals, of which last it always appears to be an essential constituent.

CHAPTER II.

NUTRITION IN VEGETABLES.

§ 1. *Food of Plants.*

The simplest kind of nutrition is that presented to us by the vegetable kingdom, where water may be considered as the general vehicle of the nutriment received. Before the discoveries of modern chemistry, it was very generally believed that plants could subsist on water alone; and Boyle, and Van Helmont, in particular, endeavoured to establish, by experiment, the truth of this opinion. The latter of these physiologists planted a willow in a certain quantity of earth, the weight of which he had previously ascertained with great care; and, during five years, he kept it moistened with rain-water alone, which he imagined was perfectly pure. At the end of this period, he found that the earth had scarcely diminished in weight, while the willow had grown into a tree, and had acquired an additional weight of one hundred and fifty pounds: whence he concluded that the water had been the only source of its nourishment. But it does not seem to have been, at that time, known, that rain-water always contains atmospheric air, and frequently, also, other substances, and that it cannot, therefore, be regarded as absolutely pure water: nor does it appear that any precautions were taken to ascertain that the water actually employed was wholly free from foreign matter, which, it is easy to conceive, it might have held in solution. In an experiment of Duhamel, on the other hand a horse-chesnut tree and an oak, exposed to the open air, and watered with distilled water alone, the former for three and the latter for eight years, were kept alive, indeed, but they were exceedingly stinted in their growth, and evidently derived little or no sustenance from the water with which they were supplied. Experiments of a similar nature were made by Bonnet, and with the like result. When plants are contained in closed vessels, and regularly supplied with water, but denied all access to carbonic acid gas, they are developed only to a very limited extent, determined by the store of nutritious matter which had been already collected in each plant when the experiment commenced, and which by combining with the water, may have afforded a temporary supply of nourishment.

But the water which nature furnishes to the vegetable organs is never perfectly pure; for, besides containing air, in which there is constantly a certain proportion of carbonic acid gas, it has always acquired by percolation through the soil various earthy and saline particles, together with materials derived from decayed vegetable or animal remains. Most of these substances are soluble, in however minute a quantity, in water: and others, finely pulverized, may be suspended in that fluid, and carried along with it into the vegetable system. It does not appear, however, that pure carbon is ever admitted; for Sir H. Davy, on mixing charcoal, ground to an impalpable powder, with the water into which the roots of mint were immersed, could not discover that the smallest quantity of that substance had been, in any case, absorbed.* But in the form of carbonic acid, this element is received in great abundance, through the medium of water, which readily absorbs it: and a considerable quantity of carbon is also introduced into the fluids of the plant, derived from the decomposed animal and vegetable materials, which the water generally contains. The peculiar fertility of each kind of soil depends principally on the quantity of these organic products it contains in a state capable of being absorbed by the plant, and of contributing to its nourishment.

* Elements of Agricultural Chemistry, Lect. VI. p. 234.

The soil is also the source whence plants derive their saline, earthy, and metallic ingredients. The silica they often contain is, in like manner, conveyed to them by the water, which it is now well ascertained, by the researches of Berzilius, is capable of dissolving a very minute quantity of this dense and hard substance. It is evident that, however small this quantity may be, if it continue to accumulate in the plant, it may in time constitute the whole amount of that which is found to be so copiously deposited on the surface, or collected in the interior of many plants, such as the bamboo, and various species of grasses. The small degree of solubility of many substances thus required for the construction of the solid vegetable fabric, is, probably, one of the reasons why plants require so large a supply of water for their subsistence.

§ 2. *Absorption of Nutriment by Plants.*

The greater number of cellular plants absorb water with nearly equal facility from every part of their surface: this is the case with the *Algæ*, for instance, which are aquatic plants. In *Lichens*, on the other hand, absorption takes place more partially; but the particular parts of the surface where it occurs are not constantly the same, and appear to be determined more by mechanical causes than by any peculiarity of structure: some, however, are found to be provided in certain parts of the surface with stomata, which De Candolle supposes may act as sucking orifices. Many mushrooms appear to be capable of absorbing fluids from all parts of their surface indiscriminately; and some species, again, are furnished at their base with a kind of radical fibrils for that purpose.

In plants having a vascular structure, which is the case with by far the greater number, the roots are the special organs to which this office of absorbing nourishment is assigned; but it occasionally happens that, under certain circumstances, the leaves, or the stems of plants are found to absorb moisture, which they have been supposed to do by the stomata interspersed on their surface. This, however, is not their natural action; and they assume it only in forced situations, when they procure no water by means of the roots, either from having been deprived of these organs, or from their being left totally dry. Thus, a branch separated from the trunk, may be preserved from withering for a long time, if the leaves be immersed in water; and when the soil has been parched by a long drought, the drooping plants will be very quickly revived by a shower of rain, or by artificial watering, even before any moisture can be supposed to have penetrated to the roots.

It is by the extremities of the roots alone, or rather by the spongioles which are there situated, that absorption takes place: for the surface of the root, being covered in every other part by a layer of epidermis, is incapable of performing this office. It was long ago remarked by Duhamel, that trees exhaust the soil only in those parts which surround the extremities of the roots: but the fact that absorption is effected only at those points has been placed beyond a doubt by the direct experiments of Sennebier, who, taking two carrots of equal size, immersed in water the whole root of the one, while only the extremity of the other was made to dip into the water, and found that equal quantities were absorbed in both cases; while, on immersing the whole surface of another carrot in the fluid, with the exception of the extremity of the root, which was raised so as to be above the surface, no absorption whatever took place. Plants having a *fusiform*, or spindle-shaped root, such as the carrot and the radish, are the best for these experiments.

In the natural progress of growth, the roots are constantly shooting forwards in the direction they have first taken, whether horizontally, or downwards, or at any other inclination. Thus, they continually arrive at new portions of soil, of which the nutritive matter has not yet been exhausted; and as a constant relation is preserved between their lateral extension and the horizontal spreading of the branches, the greater part of the rain which falls upon the tree, is made to drop from the leaves at the exact distance from the trunk, where, after it has soaked through the earth, it will be received by the extremities of the roots, and readily sucked in by the spongioles. We have here a striking instance of that beautiful correspondence, which has been established between processes belonging to different departments of nature, and which are made to concur in the production of such remote effects, as could never have been accomplished without these preconcerted and harmonious adjustments.

The spongioles, or absorbing extremities of the roots, are constructed of ordinary cellular or spongy tissue; and they imbibe the fluids, which are in contact with them, partly by capillary action, and partly, also, by what has been termed a *hygroscopic* power. But though these principles may sufficiently account for the simple entrance of the fluids, they are inadequate to explain its continued ascent through the substance of the root, or along the stem of the plant. The most probable explanation of this phenomenon is, that the progressive movement of the fluid is produced by alternate contractions and dilatations of the cells themselves, which compose the texture of the plant: these actions being themselves referrible to the vitality of the organs.

The absorbent power of the spongioles is limited by the diameter of their pores, so that fluids which are of too viscid or glutinous a consistence to pass readily through them are liable to obstruct or entirely block up these passages. Thus, if the spongioles be surrounded by a thick solution of gum, or even of sugar, its pores will be clogged up, scarcely any portion of the fluid will be absorbed, and the plant will wither and perish: but if the same liquids be more largely diluted, the watery portion will find its way through the spongioles, and become available for the sustenance of the plant, while the greater part of the thicker material will be left behind. The same apparent power of selection is exhibited when the saline solutions of a certain strength are presented to the roots: the water of the solution, with only a small proportion of the salts, being taken up, and the remaining part of the fluid being found to be more strongly impregnated with the salts than before this absorption had taken place. It would appear, however, that all this is merely the result of a mechanical operation, and that it furnishes no evidence of any discriminating faculty in the spongiole: for it is found that, provided the material presented be in a state of perfect solution and limpidity, it is sucked in with equal avidity, whether its qualities be deleterious or salubrious. Solutions of sulphate of copper, which is a deadly poison, are absorbed in large quantities by the roots of plants, which are immersed in them: and water which drains from a bed of manure, and is consequently loaded with carbonaceous particles, proves exceedingly injurious when admitted into the system of the plant, from the excess of nutriment it contains. But in the ordinary course of vegetation, no danger can arise from this general power of absorption, since the fluids which nature supplies are always such as are suitable to the organs that are to receive them.

The fluid, which is taken up by the roots, and which, as we have seen, consists chiefly of water, holding in solution atmospheric air, together with various saline and earthy ingredients necessary for the nourishment of the plant, is in a perfectly crude state. It rises in the stem of the plant, undergoing scarcely any perceptible change in its ascent; and is in this state conducted to the leaves, where it is to experience various important modifications. By causing the roots to imbibe coloured liquids, the general course of the sap has been traced with tolerable accuracy, and it is found to traverse principally the ligneous substance of the stem: in trees, its passage is chiefly through the alburnum, or more recently formed wood, and not through the bark, as was at one time believed.

The course of the sap, however, varies under different circumstances, and at different epochs of vegetation. At the period when the young buds are preparing for their development, which usually takes place when the genial warmth of spring has penetrated beyond the surface, and expanded the fibres and vessels of the plant, there arises an urgent demand for nourishment, which the roots are actively employed in supplying. As the leaves are not yet completed, the sap is at first applied to purposes somewhat different from those it is destined to fulfil at a more advanced period, when it has to nourish the fully expanded organs: this fluid has, accordingly, received a distinct appellation, being termed the *nursling sap*. Instead of rising through the alburnum, the nursling sap ascends through the innermost circle of wood, or that which is immediately contiguous to the pith, and is thence transmitted, by unknown channels, through the several layers of wood, till it reaches the buds, which it is to supply with nourishment. During this circuitous passage, it probably undergoes a certain degree of elaboration, fitting it for the office which it has to perform: it apparently combines with some nutriment, which had been previously deposited in the plant, and which it again dissolves; and thus becoming *assimilated*, is in a state proper to be incorporated with the new organization that is developing. This nursling sap, provided for the nourishment of the young buds, has been compared to the milk of animals, which is prepared for a similar purpose at those times only when nutriment is required for the rearing of their young.

Several opinions have been entertained with regard to the channels through which the sap is conveyed in its ascent along the stem, and in its passage to its ultimate destination. Many observations tend to show, that, in ordinary circumstances, it is not transmitted through any of the distinguishable vessels of the plant: for most of these, in their natural state, are found to contain only air. The sap must, therefore, either traverse the cells themselves, or pass along the intercellular spaces. That the latter is the course it takes, is the opinion of De Candolle, who adduces a variety of arguments in its support. The sap, he observes, is found to rise equally well in plants whose structure is wholly cellular; a fact which proves that vessels are not, in all cases, necessary for its conveyance. In many instances, the sap in known to deviate from its usual rectilinear path, and to pursue a circuitous course, very different from that of any of the known vessels of the plant. The diffusion of the sap in different directions, and its subsidence in the lowest parts, on certain occasions, are facts irreconcilable with the supposition that it is confined in these vessels.

Numerous experiments have been made to discover the velocity with which the sap rises in plants, and the force it exerts in its ascent. Those of Hales are well known: by lopping off the top of a young vine, and applying to the truncated extremity a glass tube, which closed round it, he found that the fluid in the tube rose to a height, which, taking into account the specific gravity of the fluid, was equivalent to a perpendicular column of water of more than forty-three feet; and, consequently, exerted a force of propulsion considerably greater than the pressure of an additional atmosphere. The velocity as well as the force of ascent, must, however, be liable to great variation; being much influenced by evaporation, and other changes, which the sap undergoes in the leaves. Various opinions have been entertained as to the agency by which the motion of the sap is effected; but, although it seems likely to be resolved into the vital movements of the cellular structure already mentioned, the question is still enveloped in considerable obscurity. There is certainly no evidence to prove that it has any analogy to a muscular power; and the simplest supposition we can make is that these actions take place by means of a contractile property belonging to the vegetable tissue, and exerted, under certain circumstances, and in conformity to certain laws, which we have not yet succeeded in determining.

§ 3. *Exhalation.*

The nutrient sap, which, as we have seen, rises in the stem, and is transmitted to the leaves without any change in its qualities or composition, is immediately, by the medium of the stomata, or orifices which abound in the surface of those organs, subjected to the process of *exhalation.* The proportion of water which the sap loses by exhalation in the leaves, is generally about two-thirds of the whole quantity received; so that it is only the remaining third that returns to nourish the organs of the plant. It has been ascertained that the water thus evaporated is perfectly pure; or, at least, does not contain more than a 10,000,000th part of the foreign matter with which it was impregnated when first absorbed by the roots. The water, thus exhaled, being dissolved by the air the moment it escapes, passes off in the form of invisible vapour. Hales made an experiment with a sunflower, three feet high, enclosed in a vessel, which he kept for fifteen days; and inferred from it that the weight of the fluid daily exhaled by the plant, was twenty ounces; and this, he computes, is a quantity seventeen times greater than that lost by insensible perspiration from an equal portion of the surface of the human body.

The comparative quantities of fluid exhaled by the same plant, at different times, are regulated, not so much by temperature, as by the intensity of the light to which the leaves are exposed. It is only during the day, therefore, that this function is in activity. De Candolle has found that the artificial light of lamps produces on the leaves an effect similar to that of the solar rays, and in a degree proportionate to its intensity.* As it is only through the stomata that exhalation proceeds, the number of these pores in a given surface must considerably influence the quantity of fluid exhaled.

By the loss of so large a portion of the water which, in the rising sap, had held in solution various foreign materials, these

* Physiologie Végétale, i. 112.

substances are rendered more disposed to separate from the fluid, and to become consolidated on the sides of the cells or vessels, to which they are conducted from the leaves. This, then, is the first modification in the qualities of the sap which it undergoes in those organs.

§ 4. *Aeration of the Sap.*

A CHEMICAL change much more considerable and important than the preceding is next effected on the sap by the leaves, when they are subjected to the action of light. It consists in the decomposition of the carbonic acid gas, which is either brought to them by the sap itself, or obtained directly from the surrounding atmosphere. In either case its oxygen is separated, and disengaged in the form of gas; while its carbon is retained, and composes an essential ingredient of the altered sap, which, as it now possesses one of the principal elements of vegetable structures, may be considered as having made a near approach to its complete *assimilation*, using this term in the physiological sense already pointed out.

The remarkable discovery that oxygen gas is exhaled from the leaves of plants during the day time, was made by the great founder of pneumatic chemistry, Dr. Priestley: to Sennebier we are indebted for the first observation that the presence of carbonic acid is required for the disengagement of oxygen in this process, and that the oxygen is derived from the decomposition of the carbonic acid, and these latter facts have since been fully established by the researches of Mr. Woodhouse, of Pennsylvania, M. Théodore de Saussure, and Mr. Palmer. They are proved in a very satisfactory manner by the following experiment of De Candolle.

Two glass jars were inverted over the same water-bath; the one filled with carbonic acid gas, the other filled with water, containing a sprig of mint; the jars communicating below by means of the water-bath, on the surface of which some oil was poured, so as to intercept all communication between the water and the atmosphere. The sprig of mint was exposed to the light of the sun for twelve days consecutively; at the end of each day the carbonic acid was seen to diminish in quantity, the water rising in the jar to supply the place of what was lost, and at the same time the plant exhaled a quantity of oxygen, exactly equal to that of the carbonic acid which had disappeared. A similar sprig of mint, placed in a jar of the same size, full of distilled water, but without having access to carbonic acid, gave out no oxygen gas, and soon perished. When, in another experiment conducted by means of the same apparatus as was used in the first, oxygen gas was substituted in the first jar instead of carbonic acid gas, no gas was disengaged in the other jar, which contained a sprig of mint. It is evident, therefore, that the oxygen gas obtained from the mint in the first experiment was derived from the decomposition, by the leaves of the mint, of the carbonic acid, which the plant had absorbed from the water.

Solar light is an essential agent in effecting this chemical change; for it is never found to take place at night, nor while the plant is kept in the dark. The experiments of Sennebier would tend to show that the violet, or most refrangible of the solar rays have the greatest power in determining this decomposition of carbonic acid; but the experiments are of so delicate a nature, that this result requires to be confirmed by a more rigid investigation, before it can be admitted as satisfactorily established.

That the carbon resulting from this decomposition of carbonic acid is retained by the plant, has been amply proved by the experiments of M. Théodore de Saussure, who found that this process is attended with a sensible increase in the quantity of carbon which the plant had previously contained.

It is in the green substance of the leaves alone that this process is conducted: a process, which, from the strong analogy that it bears to a similar function in animals, may be considered as the respiration of vegetables. The effect appears to be proportionate to the number of stomata which the plant contains. It is a process which takes place only in a living plant; for if a leaf be bruised so as to destroy its organization, and consequently its vitality, its substance is no longer capable either of decomposing carbonic acid gas under the influence of solar light, or of absorbing oxygen in the dark. Neither the roots, nor the flowers, nor any other parts of the plant, which have not this green substance at their surface, are capable of decomposing carbonic acid gas: they produce, indeed, an effect which is in some respects the opposite of this; for they have a tendency to absorb oxygen, and to convert it into carbonic acid, by uniting it with the carbon they themselves contain. This is also the case with the leaves themselves, whenever they are not under the influence of light; thus, during the whole of the night, the same leaves, which had been exhaling oxygen during the day, absorb a portion of that element. The oxygen thus absorbed enters immediately into combination with the carbonaceous matter in the plant, forming with it carbonic acid: this carbonic acid is in part exhaled; but the greater portion either remains attached to the substance of the leaf, or combines with the fluids which constitute the sap: in the latter case it is ready to be again presented to the leaf, when daylight returns, and when a fresh decomposition is again effected.

This reversal at night of what was done in the day may, at first sight, appear to be at variance with the unity of plan, which we should expect to find preserved in the vegetable economy; but a more attentive examination of the process will show that the whole is in perfect harmony, and that these contrary processes are both of them necessary, in order to produce the result intended.

The water which is absorbed by the roots generally carries with it a certain quantity of soluble animal or vegetable materials, which contain carbon. This carbon is transmitted to the leaves, where, during the night, it is made to combine with the oxygen they have absorbed. It is thus converted into carbonic acid, which, when daylight prevails, is decomposed; the oxygen being dissipated, and the carbon retained. It is evident that the object of the whole process is to obtain carbon in that precise state of disintegration, to which it is reduced at the moment of its separation from carbonic acid by the action of solar light on the green substance of the leaves; for it is in this state alone that it is available in promoting the nourishment of the plant, and not in the crude condition in which it exists when it is pumped up from the earth, along with the water which conveys it into the interior of the plant. Hence the necessity of its having to undergo this double operation of first combining with oxygen, and then being precipitated from its combination in the manner above described. It is not the whole of the carbon introduced into the vegetable system, in the form of carbonic acid, which has to undergo the first of these changes, a part of that carbon being already in the condition to which that operation would reduce it, and consequently in a state fit to receive the decomposing action of the leaves. The whole of these chemical changes may be included under the general term *Aeration.*

Thus the great object to be answered by this vegetable aeration is exactly the converse of that which we shall afterwards see is effected by the respiration of animals; in the former it is that of adding carbon, in an assimilated state, to the vegetable organization; in the latter, it is that of discharging the superfluous quantity of carbon from the animal system. The absorption of oxygen, and the partial disengagement of carbonic acid, which constitute the nocturnal changes effected by plants, must have a tendency to deteriorate the atmosphere with respect to its capability of supporting animal life; but this effect is much more than compensated by the greater quantity of oxygen given out by the same plants during the day. On the whole, therefore, the atmosphere is continually receiving from the vegetable kingdom a large accession of oxygen, and is, at the same time, freed from an equal portion of carbonic acid gas, both of which effects tend to its purification and to its remaining adapted to the respiration of animals. Nearly the whole of the carbon accumulated by vegetables is so much taken from the atmosphere, which is the primary source from which they derive that element. At the season of the year when vegetation is most active, the days are longer than the nights; so that the diurnal process of purification goes on for a greater number of hours than the nocturnal process by which the air is vitiated.

The oxygen given out by plants, and the carbonic acid resulting from animal respiration, and from the various processes of combustion which are going on in every part of the world, are quickly spread through the atmosphere, not only from the tendency of all gases to uniform diffusion, but also from the action of the winds, which are continually agitating the whole mass, and promoting the thorough mingling of its different portions, so as to render it perfectly homogeneous in every region of the globe, and at every elevation above the surface.

Thus are the two great organized kingdoms of the creation made to co-operate in the execution of the same design; each ministering to the other, and preserving that due balance in the constitution of the atmosphere, which adapts it to the welfare and activity of every order of beings, and which would soon be destroyed, were the operations of any one of them to be suspended. It is impossible to contemplate so special an adjustment of opposite effects without admiring this beautiful dispensation of Providence, extending over so vast a scale of being, and demonstrating the unity of plan on which the whole system of organized creation has been devised.

§ 5. *Return of the Sap.*

The sap, which, during its ascent from the roots, contains but a small proportion of nutritious particles, diluted with a large quantity of water, after undergoing in the leaves, as in a chemical laboratory, the double processes of exhalation and aeration, has become much more highly charged with nutriment; and that nutriment has been reduced to those particular forms and states of composition which render it applicable to the growth of the organs, and the other purposes of vegetable life. This fluid, therefore, corresponds to the blood of animals, which, like the elaborated sap, may be regarded as fluid nutriment, perfectly assimilated to that particular kind of organization, with which it is to be afterwards incorporated. From the circumstance of its being sent back from the leaves for distribution to the several organs where its presence is required, it has received the name of the *returning sap*, that it might be distinguished from the crude fluid which arrives at the leaves, and which is termed the *ascending sap*.

The returning sap still contains a considerable quantity of water, in its simple liquid form; which was necessary in order that it might still be the vehicle of various nutritive materials that are dissolved in it. It appears, however, that a large proportion of the water, which was not exhaled by the leaves, has been actually decomposed, and that its separated elements, the oxygen and the hydrogen, have been combined with certain proportions of carbon, hydrogen, nitrogen and various earths, metals and salts, so as to form the proximate vegetable products, which are found in the returning sap.

The simplest, and generally the most abundant of these products, is that which is called *Gum*.* From the universal presence of this substance in the vegetable juices, and more

* According to the investigations of Dr. Prout, 1000 grains of gum are composed of 586 grains of the elements of water, that is, of oxygen and hydrogen, in the exact proportions in which they would have united to form 586 grains of water; together with 414 of carbon, or the base of carbonic acid. This, according to the doctrine of chemical equivalents, corresponds to one molecule of water, and one molecule of carbon. Phil. Trans. for 1827, p. 584.

especially in the returning sap, of all known plants, from its bland and unirritating qualities, from its great solubility in water, and from the facility with which other vegetable products are convertible into this product, Gum may be fairly assumed to be the principal basis of vegetable nutriment; and its simple and definite composition points it out as being the immediate result of the chemical changes which the sap experiences in the leaves. During the descent of the sap, however, this fluid undergoes, in various parts of the plant, a farther elaboration, which gives rise to other products. We are now, therefore, to follow it in its progress through the rest of the vegetable system.

The returning sap descends from the leaves through two different structures: in exogenous plants the greater portion finds a ready passage through the liber, or innermost layer of bark, and another portion descends through the alburnum, or outermost layer of the wood. With regard to the exact channels through which it passes, the same degree of uncertainty prevails as with regard to those which transmit the ascending sap. De Candolle maintains that, in either case the fluids find their way through the intercellular spaces: other physiologists, however, are of opinion, that particular vessels are appropriated to the office of transmitting the descending sap. The extreme minuteness of the organs of vegetables has hitherto presented insuperable obstacles to the investigation of this important question; and consequently our reasonings respecting it can be founded only on indirect evidence. The processes of the animal economy, where the channels of distribution, and the organs of propulsion are plainly observable, afford but imperfect analogies to guide us in this intricate inquiry; for although it is true that in the higher classes of animals the circulation of the nutrient fluid, or blood, through distinct vessels, is sufficiently obvious, yet in the lower departments of the animal kingdom and in the embryo condition even of the more perfect species, the nutritious juices are distributed without being confined within any visible vessels; and they either permeate extensive cavities in the interior of the body, or penetrate through the interstices of a cellular tissue. That this latter is the mode of transmission adopted in the vegetable system has been considered probable, from the circumstance that the nutritious juices are diffused throughout those plants which contain no vessels whatsoever with the same facility as throughout those which possess vessels; from which it has been concluded that vessels are not absolutely necessary for the performance of this function. The nature of the forces which actuate the sap in its descent from the leaves, and its distribution to different parts, is involved in equal obscurity with the nature of the powers which contribute to its motion upwards along the stem, from the roots to the leaves. In endogenous plants the passage of the sap in its descent, is, in like manner, through those parts which have been latest formed; that is, through the innermost layers of their structure.

The returning sap, while traversing these several parts of the plant, deposites in each the particular materials which are requisite for their growth, and for their maintenance in a healthy condition. That portion which flows along the liber, not meeting with any ascending stream of fluid, descends without impediment to the roots, to the extension of which, after it has nourished the inner layer of bark, it particularly contributes: that portion, on the other hand, which descends along the alburnum, meets with the stream of ascending sap, which, during the day at least, is rising with considerable force. A certain mixture of these fluids probably now takes place, and new modifications are, in consequence, produced, which, from the intricacy of the chemical processes thus conducted in the inner recesses of vegetable organization, we are utterly baffled in our attempts to follow. All that we are permitted to see are the general results, namely, the gradual deposition of the materials of the future alburnum and liber. These materials are first deposited in the form of a layer of glutinous substance, termed the *Cambium;* a substance which appears to consist of the solid portion of the sap, precipitated from it by the separation of the greater part of the water that held it in solution. The cambium becomes, in process of time, more and more consolidated, and acquires the organization proper to the plant of which it now forms an integrant part: it constitutes two layers; the one, belonging to the wood, being the alburnum; the other, belonging to the bark, being the liber.

The alburnum and the liber, which have been thus constructed, perform an important part in inducing ulterior changes on the nutrient materials which the returning sap continues to supply. Their cells absorb the gummy substance from the surrounding fluid, and by their vital powers effect a still farther elaboration in its composition; converting it either into starch, or sugar, or lignin, according to the mode in which its constituent elements are arranged. Although these several principles possess very different sensible properties, yet they are found to differ but very slightly in the proportions of their ingredients; and we may infer that the real chemical alterations, which are required in order to effect these conversions, are comparatively slight, and may readily take place in the simple cellular tissue.*

In the series of decompositions which are artificially effected in the laboratory of the chemist, it has been found that gum and sugar are intermediate products, or states of transition between various others; and they appear to be peculiarly calculated, from their great solubility, for being easily conveyed from one organ to another. Starch and lignin, on the other hand, are compounds of a more permanent character, and especially adapted for being retained in the organs. Starch, which, though solid, still possesses consi-

* According to the analyses of Dr. Prout, the following is the composition of these substances: 1000 parts of

Pure Gum Arabic consists of 586 of oxygen and hydrogen, united in the proportions in which they exist in water, and 414 of carbon.

Dried Starch, or Fecula,	of 560	water, and	440	- - -	
Pure crystallized Sugar, - -	572	- - -	428	- - -	
Lignin from Boxwood, - - -	500	- - -	500	- - -	

derable solubility, is peculiarly fitted for being applied to the purposes of nourishment: it is accordingly hoarded in magazines, with a view to future employment, being to vegetables, what the fat is to animals, a resource for the exigencies which may subsequently arise. With this intention, it is carefully stored in small cells, the coats of which protect it from the immediate dissolving action of the surrounding watery sap, but allow of the penetration of this fluid, and of its solution, when required by the demands of the system. The tuberous root of the potato, that invaluable gift of Providence to the human race, is a remarkable example of a magazine of nutritive matter of this kind.

The lignin, on the contrary, is deposited with the intention of forming a permanent part of the vegetable structure, constituting the basis of the woody fibre, and giving mechanical support and strength to the whole fabric of the plant. These latter structures may be compared to the bones of animals; composing, by their union, the solid frame work, or skeleton of the organized system. The woody fibres do not seem to be capable of farther alteration in the living vegetable; and they are never, under any circumstances, taken up and removed to other parts of the system, as is the case with nutritive matter of a more convertible kind.

The sap holds in solution, besides carbonaceous matter, some saline compounds and a few earthy and metallic bases; bodies which, in however minute a quantity they may be present, have unquestionably a powerful influence in determining certain chemical changes among the elements of organic products, and in imparting to them peculiar properties; for it is now a well ascertained fact that a scarcely sensible portion of any one ingredient is capable of producing important differences in the properties of the whole compound. An example occurs in the case of gold, the ductility of which is totally destroyed by the presence of a quantity of either antimony or lead, so minute as barely to amount to the two thousandth part of the mass; and even the fumes of antimony, when in the neighbourhood of melted gold, have the power of destroying its ductility.* In the experiments made by Sir John Herschel on some remarkable motions excited in fluid conductors by the transmission of electric currents, it was found that minute portions of calcareous matter, in some instances less than the millionth part of the whole compound, are sufficient to communicate sensible mechanical motions, and definite properties to the bodies with which they are mixed.†

As Silica is among the densest and least soluble of the earths, we might naturally expect that any quantity of it taken into the vegetable system in a state of solution, would very early be precipitated from the sap, after the exhalation of the water which held it dissolved; and it is found, accordingly, that the greater portion of this silica is actually deposited in the leaves, and the parts adjacent to them. When once deposited, it seems incapable of being again taken up, and transferred to other parts, or ejected from the system; and hence, in course of time, a considerable accumulation of silicious particles takes place, and by clogging up the cells and vessels of the plant, tends more and more to obstruct the passage of nourishment into these organs. This change has been assigned as a principal cause of the decay and ultimate destruction of the leaves: their foot-stalks, more especially suffering from this obstruction, perish, and occasion the detachment of the leaves, which thus fall off at the end of each season, making way for those that are to succeed them in the next.

§ 6. *Secretion in Vegetables.*

While the powers of the simpler kinds of cells are adequate to produce in the returning sap the modifications above described, by which it is converted into gummy, saccharine, amylaceous, or ligneous products; there are other cellular organs, endowed with more extensive powers of

* Hatchett.

† Philosophical Transactions for 1824, p. 162.

chemical action, which effect still greater changes. The nature of the agents by which these changes are produced are unknown, and are therefore referred generally to the vital energies of vegetation; but the process itself has been termed *Secretion;* and the organs in which it is conducted, and which are frequently very distinguishable as separate and peculiar structures, are called *Glands.* When the products of secretion are chemically analyzed, the greater number are found to contain a large quantity of hydrogen, in addition to that which is retained in combination with oxygen as the representative of water: this is the case with all the oily secretions, whether they be fixed or volatile, and also with those secretions which are of a resinous quality. Some, on the contrary, are found to have an excess of oxygen; and this is the condition of most of the acid secretions; while others, again, appear to have acquired an addition of nitrogen.

All these substances have their respective uses, although it may frequently be difficult to assign them correctly. Some are intended to remain permanently enclosed in the vesicles where they were produced; others are retained for the purpose of being employed at some other time; while those belonging to a third class are destined to be thrown off from the system as being superfluous or noxious: these latter substances, which are presently to be noticed, are specially designated as *excretions.* Many of these fluids find their way from one part of the plant to another, without appearing to be conducted along any definite channels; and others are conveyed by vessels which apear to be specially appropriated to this office.

The following are examples of the uses to which the peculiar secretions of plants are applied. Many lichens, which fix themselves on calcareous rocks, such as the *Patellaria immersa*, are observed, in process of time, to sink deeper and deeper beneath the surface of the rock, as if they had some mode of penetrating into its substance, analogous to that which many marine worms are known to possess. The agent appears in both instances to be an acid, which here is probably the oxalic, acting upon the carbonate of lime, and producing the gradual excavation of the rock. This view is confirmed by the observation that the same species of lichen, when attached to rocks which are not calcareous, remains always at the surface, and does not penetrate below it.

A caustic liquor is sometimes collected in vesicles, situated at the base of slender hairs, having a canal which conducts the fluid to the point. This is the case with the *Nettle.* The slightest pressure made by the hand on the hairs growing on the leaves of this plant, causes the fluid in their vesicles to pass out from their points, so as to be instilled into the skin, and occasion the well known irritation which ensues. M. De Candolle, junior, has ascertained, by chemical tests, that the stinging fluid of the nettle is of an alkaline nature. In some species of this genus of plants, the hairs are so large that the whole mechanism above described is visible to the naked eye. This apparatus bears a striking resemblance to that which exists in the poisonous teeth of serpents, and which is hereafter to be described.

As the resinous secretions resist the action of water, we find them often employed by nature as a means of effectually defending the young buds from the injurious effects of moisture; and for a similar purpose we find the surface of many plants covered with a varnish of wax, which is another secretion belonging to the same class: thus, the *Ceroxylon*, and the *Iriartea* have a thick coating of wax, covering the whole of their stems. Sometimes the plant is strewed over with a bluish powder, possessing the same property of repelling water: the leaves of the *Mesembryanthemum*, or Fig-marigold, of the *Atriplex*, or Orache, and of the *Brassica*, or Cabbage, may be given as examples of this curious provision. Such plants, if completely immersed in water, may be taken out without being wetted in the slightest degree; thus presenting us with an analogy to the plumage of the cygnet, and other aquatic birds, which are rendered completely water-proof by an oily secretion spread over their surface. Many aquatic plants, as the *Batrachospermum*, are, in like manner, protected by a viscid layer, which renders the leaves slippery to the touch, and which is impermeable to water.

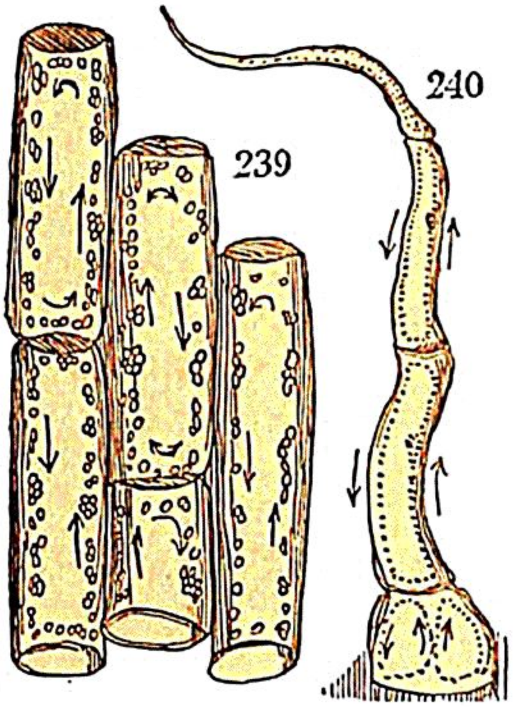
Several tribes of plants contain liquids which are opaque, and of a white milky appearance: this is the case with the *Poppy*, the *Fig-tree*, the *Convolvulus*, and a multitude of other genera; and a similar kind of juice, but of a yellow colour, is met with in the *Chelidonium*, or Celandine. All these juices are of a resinous nature, usually highly acrid, and even poisonous in their qualities; and their opacity is occasioned by the presence of a great number of minute globules, visible with the microscope. The vessels in which these fluids are contained are of a peculiar kind, and exhibit ramifications and junctions, resembling those of the blood vessels of animals. We may also discover, by the aid of the microscope, that the fluids contained in these vessels are moving in currents with considerable rapidity, as appears from the visible motions of their globules; and they present, therefore, a remarkable analogy with the circulation of the blood in some of the inferior tribes of animals. This curious phenomenon was first observed in the *Chelidonium* by Schultz, in the year 1820; and he designated it by the term *Cyclosis*, in order to distinguish it from a real *circulation*, if, on farther inquiry, it should be found not to be entitled to the latter appellation.*

The circular movements which have been thus observed in the milky juices of plants, have lately attracted much attention among botanists: but considerable doubt still prevails whether these appearances afford sufficient evidence of the existence of a general circulation of nutrient juices in the vegetable systems of those plants which exhibit them; for it would appear that in reality the observed motions of the fluid, are, in every case, partial, and the extent of the cir-

* "Die Natur der lebendigen Pflanze." See, also, Annales des Sciences Naturelles, xxiii. 75.

cuit very limited. The cause of these motions is not yet known; but probably they are ultimately referrible to a vital contraction of the vessels; for they cease the moment that the plant has received an injury, and are more active in proportion as the temperature of the atmosphere is higher.

These phenomena are universally met with in all plants that contain milky juices; but they have also been observed in many plants of which the juices are nearly transparent, and contain only a few floating globules, such as the *Chara*, or stone-wort, the *Caulinia fragilis*, &c.,* where the double currents are beautifully seen under the microscope, performing a complete circulation within the spaces of the stem that lie between two adjacent knots or joints; and where, by the proper adjustment of the object, it is easy to see at one view both the ascending and descending streams passing on opposite sides of the stem. Fig. 239 shows this circulation in the cells of the Caulinia fragilis very highly magnified, the direction of the streams being indicated by the arrows. Fig. 240 represents the circulation in one of the jointed hairs, projecting from the cuticle of the calyx of the *Tradescantia virginica*,† in each cell of which the same circulatory motion of the fluids is perceptible.



* Amici, Annales des Sciences Naturelles, ii. p. 41.

† Fig. 239 is taken from Amici, and Fig. 240 from that given by Mr. Slack, Trans. Soc. Arts, vol. xlix.

§ 7. *Excretion in Vegetables.*

It had long been conjectured by De Candolle, that the superfluous or noxious particles contained in the returning sap are excreted or thrown out by the roots. It is evident that if such a process takes place, it will readily explain why plants render the soil where they have long been cultivated less suitable to their continuance in a vigorous condition, than the soil in the same spot was originally; and also why plants of a different species are frequently found to flourish remarkably well in the same situation where this apparent deterioration of the soil has taken place. The truth of this sagacious conjecture has been established in a very satisfactory manner by the recent experiments of M. Macaire.* The roots of the *Chondrilla muralis* were carefully cleaned, and immersed in filtered rain water: the water was changed every two days, and the plant continued to flourish, and put forth its blossoms: at the end of eight days, the water had acquired a yellow tinge, and indicated, both by the smell and taste, the presence of a bitter narcotic substance, analogous to that of opium; a result which was farther confirmed by the application of chemical tests, and by the reddish brown residuum obtained from the water by evaporation. M. Macaire ascertained that neither the roots nor the stems of the same plants, when completely detached, and immersed in water, could produce this effect, which he therefore concludes is the result of an exudation from the roots, continually going on while the plant is in a state of healthy vegetation. By comparative experiments on the quantity of matter thus exerted by the roots of the French bean (*Phaseolus vulgarus*) during the night and the day, he found it to be much more considerable at night; an effect which it is natural to ascribe to the interruption in the action of the leaves when they are deprived of light, and when the cor-

* An account of these experiments was first published in the fifth volume of the "Mémoires de la Société de Physique et d'Histoire Naturelle de Genève," and repeated in the "Annales des Sciences Naturelles," xxviii. 402.

responding absorption by the roots is also suspended. This was confirmed by the result of some experiments he made on the same plants by placing them, during day time, in the dark; under which circumstances the excretion from the roots was found to be immediately much augmented: but, even when exposed to the light, there is always some exudation, though in small quantity, going on from the roots.

That plants are able to free themselves, by means of this excretory process, from noxious materials, which they may happen to have imbibed through the roots, was also proved by another set of experiments on the *Mercurialis annua*, the *Senecio vulgaris*, and *Brassica campestris*, or common cabbage. The roots of each specimen, after being thoroughly washed and cleaned, were separated into two bunches, one of which was put into a diluted solution of acetate of lead, and the other into pure water, contained in a separate vessel. After some days, during which the plants continued to vegetate tolerably well, the water in the latter vessel being examined, was found to contain a very perceptible quantity of the acetate of lead. The experiment was varied by first allowing the plant to remain with its roots immersed in a similar solution, and then removing it, (after carefully washing, in order to free the roots from any portion of the salt that might have adhered to their surface,) into a vessel with rain water; after two days, distinct traces of the acetate of lead were afforded by the water. Similar experiments were made with lime-water and with a solution of common salt, instead of the acetate of lead, and were attended with the like results. De Candolle has ascertained, that certain maritime plants which yields soda, and which flourish in situations very distant from the coast, provided they occasionally receive breezes from the sea, communicate a saline impregnation to the soil in their immediate vicinity, derived from the salt which they doubtless had imbibed by the leaves.

Although the materials which are thus excreted by the roots are noxious to the plant which rejects them, and would consequently be injurious to other individuals of the same species, it does not therefore follow that they are incapable of supplying salutary nourishment to other kinds of plants: thus, it has been observed that the *Salicaria* flourishes particularly in the vicinity of the willow; and the *Orobanche*, or broom-rape, in that of hemp. This fact has also been established experimentally by M. Macaire, who found that the water in which certain plants had been kept was noxious to other specimens of the same species, while on the other hand, it produced a more luxuriant vegetation in plants of a different kind.

This fact is of great importance in the theory of agriculture, since it perfectly explains the advantage derived from a continued rotation of different crops in the same field, in increasing the productiveness of the soil. It also gives a satisfactory explanation of the curious phenomenon of *fairy rings*, as they are called; that is, of circles of dark green grass, occurring in old pastures: these Dr. Wollaston has traced to the growth of successive generations of certain *fungi*, or mushrooms spreading from a central point.* The soil, which has once contributed to the support of these fungi, becomes exhausted or deteriorated with respect to the future crops of the same species, and the plants, therefore, cease to be produced on those spots; the second year's crop consequently appears in the space of a small ring, surrounding the original centre of vegetation; and in every succeeding year, the deficiency of nutriment on one side necessarily causes the new roots to extend themselves solely in the opposite direction, and occasions the circle of fungi continually to proceed by annual enlargement from the centre outwards. An appearance of luxuriance of the grass follows as a natural consequence; for the soil of an interior circle will always be enriched and fertilized with respect to the culture of grass by the decayed roots of fungi of the preceding years' growth. It often happens, indeed, during the growth of these fungi, that they so completely absorb all nutriment from the soil beneath, that the herbage is for a time totally destroyed,

* Phil. Trans. for 1807, p. 133.

giving rise to the appearance of a ring bare of grass, surrounding the dark ring; but after the fungi have ceased to appear, the soil where they had grown becomes darker, and the grass soon vegetates again with peculiar vigour. When two adjacent circles meet and interfere with each other's progress, they not only do not cross each other, but both circles are invariably obliterated between the points of contact; for the exhaustion occasioned by each obstructs the progress of the other, and both are starved. It would appear that different species of fungi often require the same kind of nutriment; for in cases of the interference of a circle of mushrooms with another of puff-balls, still the circles do not intersect one another; the exhaustion produced by the one being equally detrimental to the growth of the other, *as if it had been occasioned by the previous vegetation of* its own species.

The only final cause we can assign for the series of phenomena constituting the nutritive functions of vegetables is the formation of certain organic products calculated to supply sustenance to a higher order of beings. The animal kingdom is altogether dependent for its support, and even existence, on the vegetable world. Plants appear formed to bring together a certain number of elements derived from the mineral kingdom, in order to subject them to the operations of vital chemistry, a power too subtle for human science to detect, or for human art to imitate; and by which these materials are combined into a variety of nutritive substances. Of these substances, so prepared, one portion is consumed by the plants themselves in maintaining their own structures, and in developing the embryos of those which are to replace them; another portion serves directly as food to various races of animals; and the remainder is either employed in fertilizing the soil, and preparing it for subsequent and more extended vegetation, or else, buried in the bosom of the earth, it forms part of that vast magazine, of combustible matter, destined to benefit future communities of mankind, when the arts of civilization shall have developed the mighty energies of human power.

CHAPTER III.

ANIMAL NUTRITION IN GENERAL.

§ 1. *Food of Animals.*

NUTRITION constitutes no less important a part of the animal, than of the vegetable economy. Endowed with more energetic powers, and enjoying a wider range of action, animals, compared with plants, require a considerably larger supply of nutritive materials for their sustenance, and for the exercise of their various and higher faculties. The materials of animal nutrition must, in all cases, have previously been combined in a peculiar mode; which combination the powers of organization alone can effect. In the conversion of vegetable into animal matter, the principal changes in chemical composition which the former undergoes, are, first, the abstraction of a certain proportion of carbon; and secondly, the addition of nitrogen.* Other changes, however, less easily appreciable, though perhaps as important as the former, take place to a great extent, with regard to the proportions of saline earthy, and metallic ingredients; all of which, and more especially iron, exist in greater quantity in animal than in vegetable bodies. The former also contain a larger proportion of sulphur and phosphorus than the latter.

* The recent researches of Messrs. Macaire and Marcet tend to establish the important fact that both the chyle and the blood of herbivorous and of carnivorous quadrupeds are identical in their chemical composition, in as far, at least, as concerns their ultimate analysis. They found, in particular, the same proportion of nitrogen in the chyle, whatever kind of food the animal habitually consumed; and it was also the same in the blood, whether of carnivorous or herbivorous animals; although this last fluid contains more nitrogen than the chyle. (*Mémoires de la Société de Physique et d'Histoire Naturelle de Genève*, v. 389.)

The equitable mode in which nature dispenses to her innumerable offspring the food she has provided for their subsistence, apportioning to each the quantity and the kind most consonant to enlarged views of prospective beneficence, is calculated to excite our highest wonder and admiration. While the waste is the smallest possible, we find that nothing which can afford nutriment is wholly lost. There is no part of the organized structure of an animal or vegetable, however dense its texture, or acrid its qualities, that may not, under certain circumstances, become the food of some species of insect, or contribute in some mode to the support of animal life. The more succulent parts of plants, such as the leaves, or softer stems, are the principal sources of nourishment to the greater number of larger quadrupeds, to multitudes of insects, as well as to numerous tribes of other animuls. Some plants are more particularly designed as the appropriate nutriment of particular species, which would perish if these ceased to grow: thus the silkworm subsists almost exclusively upon the leaves of the mulberry tree; and many species of caterpillars are respectively attached each to a particular plant which they prefer to all others. There are at least fifty different species of insects that feed upon the common nettle; and plants, of which the juices are most acrid and poisonous to the generality of animals, such as *Euphorbium*, *Henbane*, and *Nightshade*, afford a wholesome and delicious food to others. Innumerable tribes of animals subsist upon fruits and seeds; while others feast upon the juices which they extract from flowers, or other parts of plants; others, again, derive their principal nourishment from the hard fibres of the bark or wood.

Still more general is the consumption of animal matter by various animals. Every class has its carnivorous tribes, which consume living prey of every denomination; some being formed to devour the flesh of the larger species, whether quadrupeds, birds, or fish; others feeding on reptiles or mollusca, and some satisfying their appetites with insects alone. The habits of the more diminutive tribes are not less predatory and voracious than those of the larger quadrupeds; for the spiders on the land, and the crustacea in the sea are but representatives of the lions and tigers of the forest, displaying an equally ferocious and insatiable rapacity. Other families, again, generally of still smaller size, are designed for a parasitic existence, their organs being fitted only for imbibing the blood or juices of other animals.

No sooner is the signal given, on the death of any large animal, than multitudes of every class hasten to the spot, eager to partake of the repast which nature has prepared. If the carcass be not rapidly devoured by rapacious birds, or carnivorous quadrupeds, it never fails to be soon attacked by swarms of insects, which speedily consume its softer textures, leaving only the bones.* These, again, are the favourite repast of the Hyena, whose powerful jaws are peculiarly formed for grinding them into powder, and whose stomach can extract from them an abundant portion of nutriment. No less speedy is the work of demolition among the inhabitants of the waters, were innumerable fishes, crustacea, annelida, and mollusca, are on the watch to devour all dead animal matter which may come within their reach. The consumption of decayed vegetables is not quite so speedily accomplished; yet these, also, afford an ample store of nourishment to hosts of minuter beings, less conspicuous, perhaps, but performing a no less important part in the economy of the creation. It may be observed that most of the insects which feed on decomposing materials, whether animal or vegetable, consume a much larger quantity than

* So strongly was Linnæus impressed with the immensity of the scale on which these works of demolition by insects are carried on in nature, that he used to maintain that the carcass of a dead horse would not be devoured with the same celerity by a lion, as it would by three flesh flies (*Musca vomitoria*) and their immediate progeny: for it is known that one female fly will give birth to at least 20,000 young larvæ, each of which will, in the course of a day, devour so much food, and grow so rapidly, as to acquire an increase of two hundred times its weight: and a few days are sufficient for the production of a third generation.

they appear to require for the purposes of nutrition. We may hence infer that, in their formation, other ends were contemplated, besides their own individual existence. They seem as if commissioned to act as the scavengers of organic matter, destined to clear away all those particles, of which the continued accumulation would have tainted the atmosphere, or the waters, with infection, and spread a wide extent of desolation and of death.

In taking these general surveys of the plans adopted by nature for the universal subsistence of the objects of her bounty, we cannot help admiring how carefully she has provided the means for turning to the best account every particle of each product of organic life, whether the material be consumed as food by animals, or whether it be bestowed upon the soil, reappearing in the substance of some plant, and being in this way made to contribute, eventually, to the same ultimate object, namely, the support of animal life.

But we may carry these views still farther, and following the ulterior destination of the minuter and unheeded fragments of decomposed organizations, which we might conceive had been cast away, and lost to all useful purposes, we may trace them as they are swept down by the rains, and deposited in pools and lakes, amidst waters collected from the soil on every side. Here we find them, under favourable circumstances, again partaking of animation, and invested with various forms of infusory animalcules, which sport, in countless myriads, their ephemeral existence, within the ample regions of every drop. Yet, even these are still qualified to fulfil other objects in a more distant and far wider sphere; for, borne along, in the course of time, by the rivers into which they pass, they are at length conveyed into the sea, the great receptacle of all the particles that are detached from the objects on land. Here, also, they float not uselessly in the vast abyss, but contribute to maintain in existence incalculable hosts of animal beings, which people every portion of the wide expanse of ocean, and which rise, in regular gradation, from the microscopic monad, and scarcely visible medusa,* through endless tribes of mollusca, and of fishes, up to the huge Leviathan of the deep.

Even those portions of organic matter, which, in the course of decomposition, escape in the form of gases, and are widely diffused through the atmosphere, are not wholly lost for the uses of living nature: for, in course of time, they, also, as we have seen, re-enter into the vegetable system, resuming the solid form, and reappearing as organic products, destined again to run through the same never ending cycle of vicissitudes and transmutations.

The diffusion of animals over wide regions of the globe is a consequence of the necessity which prompts them to search for subsistence wherever food is to be met with. Thus while the vegetation of each different climate is regulated by the seasons, herbivorous animals are in the winter forced to migrate from the colder to the milder regions, where they may find the pasturage they require; and these migrations occasion corresponding movements among the predaceous tribes which subsist upon them. Thus are continual interchanges produced, contributing to colonize the earth, and extend its animal population over every habitable district. But in all these changes we may discern the ultimate relation they ever bear to the condition of the vegetable world, which is placed as an intermediate and necessary link between the mineral and the animal kingdoms. All those regions which are incapable of supporting an extensive vegetation, are, on that account, unfitted for the habitation of animals. Such are the vast continents of ice, which spread around the poles; such are the immense tracts of snow and of glaciers, which occupy the summits of the highest mountain chains; and such is the wide expanse of sand, which covers the largest portions both of Africa and

* The immensity of the numbers of these microscopic medusæ, which people every region of the ocean, may be judged of from the phenomenon of the phosphorescent light which is so frequently exhibited by the sea, when agitated, and which, as I have already observed, is found to arise from the presence of an incalculable multitude of these minute animals.

of Asia: and often have we heard of the sunken spirits of the traveller through the weary desert, from the appalling silence that reigns over those regions of eternal desolation; but no sooner is his eye refreshed by the reappearance of vegetation, than he again traces the footsteps and haunts of animals, and welcomes the cheering sound of sensitive beings.

The kind of food which nature has assigned to each particular race of animals has an important influence, not merely on its internal organization, but, also, on its active powers and disposition; for the faculties of animals, as well as their structure, have a close relation to the circumstances connected with their subsistence, such as the abundance of its supply, the facility of procuring it, the dangers incurred in its search, and the opposition to be overcome before it can be obtained. In those animals whose food lies generally within their reach, the active powers acquire but little development: such, for instance, is the condition of herbivorous quadrupeds, whose repast is spread every where in rich profusion beneath their feet; and it is the chief business of their lives to crop the flowery mead, and repose on the same spot which affords them the means of support. Predaceous animals on the contrary, being prompted by the calls of appetite to wage war with living beings, are formed for a more active and martial career; their muscles are more vigorous, their bones are stronger, their limbs more robust, their senses more delicate and acute. What sight can compare with that of the eagle and the lynx; what scent can be more exquisite than that of the wolf and the jackal? All the perceptions of carnivorous animals are more accurate, their sagacity embraces a greater variety of objects, and, in feats of strength and agility, they far surpass the herbivorous tribes. A tiger will take a spring of fifteen or twenty feet, and, seizing upon a buffalo, will carry it with ease on its back through a dense and tangled thicket: with a single blow of its paw it will break the back of a bull, or tear open the flanks of an elephant.

While herbivorous animals are almost constantly employed in eating, carnivorous animals are able to endure abstinence for a great length of time, without any apparent diminution of their strength: a horse or an ox would sink under the exhaustion consequent upon fasting for two or three days, whereas, the wolf and the martin have been known to live fifteen days without food, and a single meal will suffice them for a whole week. The calls of hunger produce on each of these classes of animals the most opposite effects. Herbivorous animals are rendered weak and faint by the want of food, but the tiger is roused to the full energy of his powers by the cravings of appetite; his strength and courage are never so great as when he is nearly famished, and he rushes to the attack, reckless of consequences, and undismayed by the number or force of his opponents. From the time he has tasted blood, no education can soften the native ferocity of his disposition: he is neither to be reclaimed by kindness, nor subdued by the fear of punishment. On the other hand, the elephant, subsisting upon the vegetable productions of the forest, superior in size and even in strength to the tiger, and armed with as powerful weapons of offence, which it wants not the courage to employ, when necessary, is capable of being tamed with the greatest ease, is readily brought to submit to the authority of man, and requites with affection the benefits he receives.

On first contemplating this extensive destruction of animal life, by modes the most cruel and revolting to all our feelings, we naturally recoil with horror from the sanguinary scene; and cannot refrain from asking how all this is consistent with the wisdom and benevolence so conspicuously manifested in all other parts of the creation. The best theologians have been obliged to confess that a difficulty does here exist,* and that the only plausible solution which it admits of, is to consider the pain and suffering thus created, as one of the necessary consequences of those general laws

* See, in particular, Paley's Natural Theology, chap. xxvi.

which secure, on the whole, the greatest and most permanent good. There can be no doubt that the scheme, by which one animal is made directly conducive to the subsistence of another, leads to the extension of the benefits of existence to an infinitely greater number of beings than could otherwise have enjoyed them. This system, besides, is the spring of motion and activity in every part of nature. While the pursuit of its prey forms the occupation, and constitutes the pleasure of a considerable part of the animal creation, the employment of the means they possess of defence, of flight, and of precaution, is also the business of a still larger part. These means are, in a great proportion of instances, successful; for, wherever nature has inspired sagacity in the perception of danger, she has generally bestowed a proportionate degree of ingenuity in devising the means of safety. Some are taught to deceive the enemy, and to employ stratagem where force or swiftness would have been unavailing: many insects, when in danger, counterfeit death, to avoid destruction; others, among the myriapoda, fold themselves into the smallest possible compass, so as to escape detection. The tortoise, as we have already seen, retreats within its shell, as within a fortress; the hedge-hog rolls itself into a ball, presenting bristles on every side; the diodon inflates its globular body for the same purpose, and floats on the sea, armed at all the points of its surface; the cuttle-fish screens itself from pursuit by effusing an intensely dark coloured ink, which renders the surrounding waters so black and turbid as to conceal the animal, and favour its escape; the torpedo defends itself from molestation by reiterated discharges from its electric battery; the butterfly avoids capture by its irregular movements in the air, and the hare puts the hounds at fault by her mazy doublings. Thus does the animated creation present a busy scene of activity and employment: thus are a variety of powers called forth, and an infinite diversity of pleasures derived from their exercise; and existence is, on the whole, rendered the source of incomparably higher degrees, as well as of a larger amount of enjoyment, than appears to have been compatible with any other imaginable system.

§ 2. *Series of Vital Functions.*

In the animal economy, as in the vegetable, the vital, or nutritive functions are divisible into seven kinds, namely, Assimilation, Circulation, Respiration, Secretion, Excretion, Absorption, and Nutrition; some of which even admit of farther subdivision. This is the case more particularly with the processes of assimilation, which are generally numerous, and require a very complicated apparatus for acting on the food in all the stages of its conversion into blood, a fluid which, like the returning sap of plants, consists of nutriment in its completely assimilated state. It will be necessary, therefore, to enter into a more particular examination of the objects of these different processes.

In the more perfect structures belonging to the higher orders of animals, contrivances must be adopted, and organs provided for seizing the appropriate food, and conveying it to the mouth. A mechanical apparatus must there be placed for effecting that minute subdivision, which is necessary to prepare it for the action of the chemical agents to which it is afterwards to be subjected. From the mouth, after it has been sufficiently masticated, and softened by fluid secretions prepared by neighbouring glands, the food must be conveyed into an interior cavity, called the *Stomach*, where, as in a chemical laboratory, it is made to undergo the particular change which results from the operation termed *Digestion*. The digested food must thence be conducted into other chambers, composing the intestinal tube, where it is converted into *Chyle*, which is a milky fluid, consisting wholly of nutritious matter. Vessels are then provided, which, like the roots of plants, drink up this prepared fluid, and convey it to other cavities capable of imparting to it a powerful impulsive force, and of distributing it through appropriate channels of circulation, not only to the respiratory organs, where its elaboration is completed by the influence of atmospheric air, but also to all other parts of the system, where such a supply is required for their maintenance in the living state. The objects of these subsequent functions, many of which are peculiar to animal life, have already been detailed.*

This subdivision of the assimilatory processes occurs only in the higher classes of animals, for in proportion as we descend in the scale, we find them more and more simplified, by the concentration of organs, and the union of many offices in a single organ, till we arrive, in the very lowest orders, at little more than a simple digestive cavity, performing at once the functions of the stomach and of the heart; without any distinct circulation of nutrient juices, without vessels,—nay, without any apparent blood. Long after all the other organs, such as the skeleton, whether internal or external, the muscular and nervous systems, the glands, vessels, and organs of sense, have one after another disappeared, we still continue to find the digestive cavity retained, as if it constituted the most important, and only indispensable organ of the whole system.

The possession of a stomach, then, is the peculiar characteristic of the animal system as contrasted with that of vegetables. It is a distinctive criterion that applies even to the lowest orders of zoophytes, which, in other respects, are so nearly allied to plants. It extends to all insects, however diminutive; and even to the minutest of the microscopic animalcules.†

The mode in which the food is received into the body is, in general, very different in the two organized kingdoms of nature. Plants receive their nourishment by a slow, but

* See the first chapter of this volume, p. 23.

† In some species of animals belonging to the tribe of medusæ, as the *Eudora*, *Berenice*, *Orythia*, *Favonia*, *Lymnoria*, and *Geryonia*, no central cavity corresponding to a stomach has been discovered: they appear, therefore, to constitute an exception to the general rule. See Péron, Annales de Muséum, xiv. 227 and 326.

nearly constant supply, and have no receptacle for collecting it at its immediate entry; the sap, as we have seen passing at once into the cellular tissue of the plant, where the process of its gradual elaboration is commenced. Animals, on the other hand, are capable of receiving at once large supplies of food, in consequence of having an internal cavity, adapted for the immediate reception of a considerable quantity. A vegetable may be said to belong to the spot from which it imbibes its nourishment, and the surrounding soil, into which its absorbing roots are spread on every side, may almost be considered as a part of its system. But an animal has all its organs of assimilation within itself, and having receptacles in which it can lay in a store of provisions, it may be said to be nourished from within; for it is from these interior receptacles that the lacteals, or absorbing vessels, corresponding in their office to the roots of vegetables, imbibe nourishment. Important consequences flow from this plan of structure; for since animals are thus enabled to subsist for a certain interval without needing any fresh supply, they are independent of local situation, and may enjoy the privilege of moving from place to place. Such a power of locomotion was, indeed, absolutely necessary to beings which have their subsistence to seek. It is this necessity, again, that calls for the continued exercise of their senses, intelligence, and more active energies; and that leads, in a word, to the possession of all those higher powers which raise them so far above the level of the vegetable creation.

CHAPTER IV.

Nutrition in the lower Orders of Animals.

THE animals which belong to the order of polypi present us with the simplest of all possible forms of nutritive organs. The hydra, for instance, which may be taken as the type of this formation, consists of a mere stomach, provided with the simplest instruments for catching food,—and nothing more. A simple sac, or tube, adapted to receive and digest food, is the only visible organ of its body. It exhibits not a trace of either brain, nerves, or organs of sense, nor any part corresponding to lungs, heart, or even vessels of any sort; all these organs, so essential to the maintenance of life in other animals, being here dispensed with. In the magnified view of the hydra, exhibited in Fig. 241, the cavity into which the food is received and digested is laid open by a longitudinal section, so as to show the comparative thickness of the walls of this cavity. The structure of these walls must be adapted not only to prepare and pour out the fluids by which the food is digested, but also to allow of the transudation through its substance, probably by means of invisible pores, of the nutritious particles thus extracted from the food, for the purpose of its being incorporated and identified with the gelatinous pulp, of which the body appears wholly to consist.

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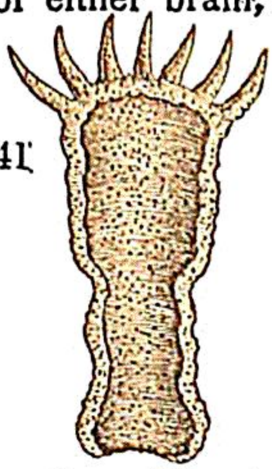
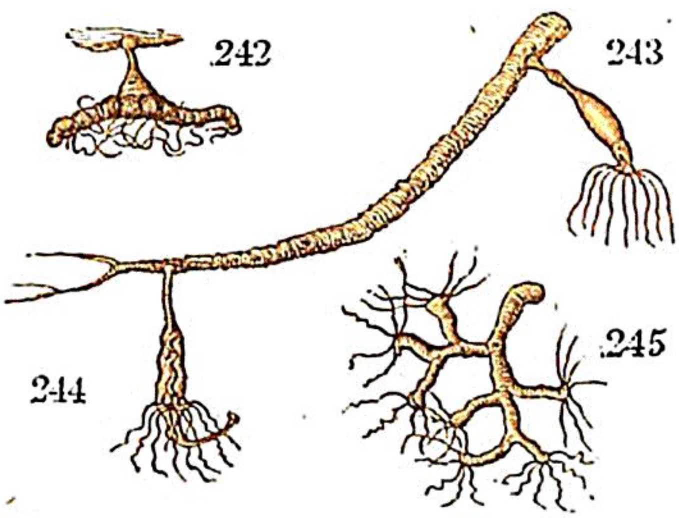


The thinness and transparency of the walls of this cavity allow of our distinctly following these changes by the aid of the microscope. Trembley watched them with unwearied perseverance for days together, and has given the following account of his observations. The hydra, though it does not pursue the animals on which it feeds, yet devours with avidity all kinds of living prey that come within the reach of its tentacula, and which it can overcome and introduce into its mouth. The larvæ of insects, naides, and other aquatic worms, minute crustacea, and even small fishes, are indiscriminately laid hold of, if they happen but to touch any part of the long filaments which the animal spreads out, in different directions, like a net in search of food. The struggles of the captive which finds itself entangled in the folds of these tentacula, are generally ineffectual, and the hydra, like the boa constrictor, contrives, by enormously expanding its mouth, slowly to draw into its cavity animals much larger than its own body. Worms longer than itself are easily swallowed by being previously doubled together by the tentacula. Fig. 242 shows a hydra in the act of devouring the vermiform larva of a *Tipula,* which it has en-



circled with its tentacula, to which it has applied its expanded mouth, and of which it is absorbing the juice, before swallowing it. Fig. 243 shows the same animal, after it has succeeded, though not without a severe contest, in swallowing a minnow, or other small fish, the form of which is still visible through the transparent sides of the body, which are stretched to the utmost. It occasionally happens, when two of these animals have both seized the same object by its different ends, that a struggle between them ensues, and that the stronger, having obtained the victory, swallows at a single gulp, not only the object of contention, but its antagonist also. This scene is represented in Fig. 244, where the tail of the hydra, of which the body has been swallowed by the victor, is seen protruding from the mouth of the latter. It soon, however, extricates itself from this situation, apparently without having suffered the smallest injury. The voracity of the hydra is very great, especially after long fasting; and it will then devour a great number of insects, one after another, at one meal, gorging itself till it can hold no more, and its body becoming dilated to an extraordinary size; and yet the same animal can continue to live for more than four months without any visible supply of food.

On attentively observing the changes induced upon the food by the action of the stomach of these animals, they appear to consist of a gradual melting down of the softer parts, which are resolved into a kind of jelly, leaving unaltered only a few fragments of the harder and less digestible parts. These changes are accompanied by a kind of undulation of the contents of the stomach, backwards and forwards, throughout the whole tube, apparently produced by the contraction and dilatation of its different portions. The undigested materials being collected together and rejected by the mouth, the remaining fluid is seen to contain opaque globules of various sizes, some of which are observed to penetrate through the sides of the stomach, and enter into the granular structure which composes the flesh of the animal. Some portion of this opaque fluid is distributed to the tentacula, into the tubular cavities of which it may be seen entering by passages of communication with the stomach. By watching attentively the motions of the globules, it will be perceived that they pass backwards and forwards through these passages, like ebbing and flowing tides.

All these phenomena may be observed with greater distinctness when the food of the animal contains colouring matter, capable of giving a tinge to the nutritious fluid, and allowing of its progress being traced into the granules which are dispersed throughout the substance of the body. Trembley is of opinion that these granules are vesicular, and that they assume the colour they are observed to have, from their becoming filled with the coloured particles contained in the nourishment. The granules which are nearest to the cavity of the stomach are those which are first tinged, and which therefore first imbibe the nutritious juices: the others are coloured successively, in an order determined by their distance from the surface of the stomach. Trembley ascertained that a living hydra introduced into the stomach of another hydra, was not in any degree acted upon by the fluid secretions of that organ, but came out uninjured. It often happens that a hydra, in its eagerness to transfer its victim into its stomach, swallows several of its own tentacula, which had encircled it; but these tentacula always ultimately come out of the stomach, sometimes after having remained there twenty-four hours, without the least detriment.

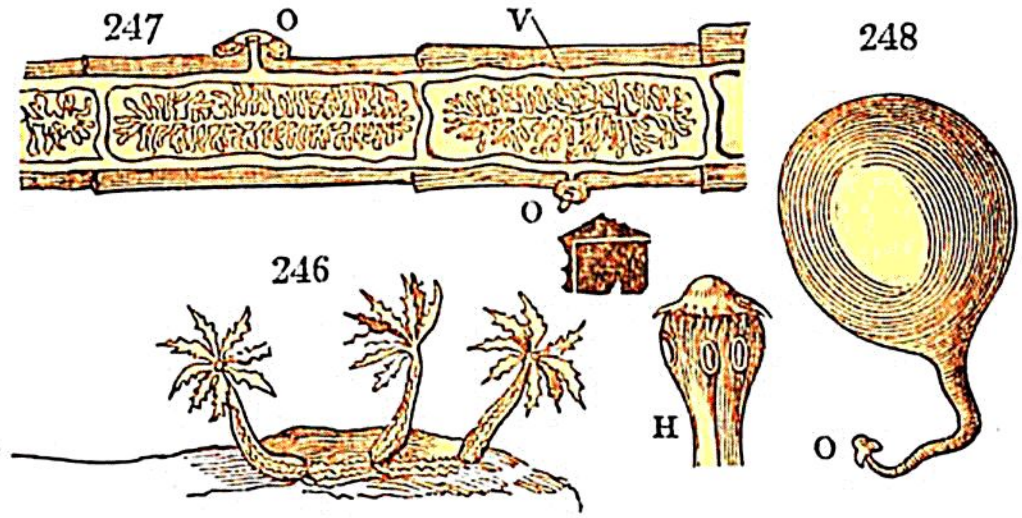
The researches of Trembley have brought to light the extraordinary fact that not only the internal surface of the stomach of the polypus is endowed with the power of digesting food, but that the same property belongs also to the external surface, or what we might call the skin of the animal. He found that by a dexterous manipulation, the hydra may be completely turned inside out, like the finger of a glove, and that the animal, after having undergone this singular operation, will very soon resume all its ordinary functions, just as if nothing had happened. It accommodates itself in the course of a day or two to the transformation, and resumes all its natural habits, eagerly seizing animalcules with its tentacula, and introducing them into its newly formed stomach, which has for its interior surface what before was the exterior skin, and which digests them with perfect ease. When the discovery of this curious phenomenon was first made known to the world, it excited great astonishment, and many naturalists were incredulous as to the correctness of the observations. But the researches of Bonnet and of Spallanzani, who repeated the experiments of Trembley, have borne ample testimony to their accuracy, which those of every subsequent observer have farther contributed to confirm.

The experiments of Trembley have also proved that every portion of the hydra possesses a wonderful power of reparing all sorts of injuries, and of restoring parts which have been removed. These animals are found to bear with impunity all sorts of mutilations. If the tentacula be cut off, they grow again in a very short time: the whole of the fore part of the body is, in like manner, reproduced, if the animal be cut asunder; and from the head which has been removed there soon sprouts forth a new tail. If the head of the hydra be divided by a longitudinal section, extending only half way down the body, the cut portions will unite at their edges, so as to form two heads, each having its separate mouth, and set of tentacula. If it be split into six or seven parts, it will become a monster with six or seven heads; if each of these be again divided, another will be formed with double that number. If any of the parts of this compound polypus be cut off, as many new ones will spring up to replace them; the mutilated heads at the same time acquiring fresh bodies, and becoming as many entire polypi. Fig. 245 represents a hydra with seven heads, the result of several operations of this kind. The hydra will sometimes of its own accord split into two; each division becoming independent of the other, and growing to the same size as the original hydra. Trembley found that different portions of one polype might be ingrafted on another, by cutting their surfaces, and pressing them together; for by this means they quickly unite, and become a compound animal. When the body of one hydra is introduced into the mouth of another, so that their heads are kept in contact for a sufficient length of time, they unite and form but one individual. A number of heads and bodies may thus be joined together artificially, so as to compose living monsters more complicated than the wildest fancy has conceived.

Still more complicated are the forms and economy of those many-headed monsters, which prolific nature has spread in countless multitudes over the rocky shores of the ocean, in every part of the globe. These aggregated polypi grow in imitation of plants, from a common stem, with widely extended flowering branches. Myriads of mouths open upon the surface of the animated mass; each mouth being surrounded with one or more circular rows of tentacula, which are extended to catch their prey: but as the stationary condition of these polypes prevents them from moving in search of food, their tentacula are generally furnished with a multitude of cilia, which, by their incessant vibrations, determine currents of water to flow towards the mouth, carrying with them the floating animalcules on which the entire polypus subsists.

Each mouth leads into a separate stomach; whence the food, after its digestion, passes into several channels, generally five in number, which proceed in different directions from the cavity of each stomach, dividing into many branches, and being distributed over all the surrounding portions of the flesh. These branches communicate with similar channels proceeding from the neighbouring stomachs: so that the food which has been taken in by one of the mouths, contributes to the general nourishment of the whole mass of aggregated polypi. Cuvier discovered this structure in the *Veretilla* which belongs to this order of polypi: he also found it in the *Pennatula*, and it is probably similar in all the others. Fig. 246 represents three of the polypes of the Veretilla, with their communicating vessels seen below. The prevailing opinion among naturalists is, that each polypus is an individual animal, associated with the rest in a sort of republic, where the labours of all are exerted for the common benefit of the whole society. But it is, perhaps, more consonant with our ideas of the nature of vitality, to consider the extent of the distribution of nutritive fluid in any organic system, as the criterion of the individuality of that system, a view which would lead us to consider the entire polypus, or mass composed of numerous polypes, as a single individual animal; for there is no more inconsistency in supposing that an individual animal may possess any number of mouths, than that it may be provided with a multitude of distinct stomachs, as we shall presently find is actually exemplified in many of the lower animals.

Some of the *Entozoa*, or parasitic worms, exhibit a general diffusion, or circulation of nourishment through numerous channels of communication, into which certain absorbing



vessels convey it from a great number of external orifices, or mouths, as they may be called. This is the case with the *Tænia*, or tape worm, which is composed of a series of flat jointed portions, of which two contiguous segments are seen, highly magnified, in Fig. 247, exhibiting round the margin of each portion, a circle of vessels (v,) which communicate with those of the adjoining segments; each circle being provided with a tube (o,) having external openings for imbibing nourishment from the surrounding fluids. Although each segment is thus provided with a nutritive apparatus, complete within itself, and so far, therefore, independent of the rest, the individuality of the whole animal is sufficiently determined by its having a distinct head at one extremity, provided with instruments for its attachment to the surfaces it inhabits.

The *Hydatid*, (Fig. 248,) is another parasitic worm, of the simplest possible construction. It has a head (o,) of which H is a magnified representation, furnished with four suckers, and a tubular neck, which terminates in a globular sac. When this sac, which is the stomach, is fully distended with fluid, its sides are stretched, so as to be reduced to a very thin transparent membrane, having a perfectly spherical shape: after this globe has become swollen to a very large size, the neck yields to the distention, and disappears; and the head can then be distinguished only as a small point on the surface of the globular sac. It is impossible to conceive a more simple organic structure than this, which may, in fact, be considered as an isolated living stomach. The *Cœnurus*, which is found in the brain of sheep, has a structure a little more complicated; for, instead of a single head, there are a great number spread over the surface, opening into the same general cavity; and when the sac is distended, appearing only as opaque spots on its surface.

The structure of the *Sponge* has been already fully described; and the course of the minute channels pointed out, in which a kind of circulation of sea water is carried on for the nourishment of the animal. The mode by which nutriment is extracted from this circulating fluid, and made to contribute to the growth of these plant-like structures, is entirely unknown.

The apparatus for nutrition possessed by animals belonging to the tribe of *Medusæ* is of a peculiar kind. I have already described the more ordinary form of these singular animals, which resembles a mushroom, from the hemispherical form of their bodies, and their central foot-stalk, or pedicle. In the greater number of species there exists at the extremity of this pedicle, a single aperture, which is the beginning of a tube leading into a large central cavity in the interior of the body, and which may, therefore, be regarded as the mouth of the animal; but in those species which have no pedicle, as the *Æquorea*, the mouth is situated at the centre of the under surface. The aperture is of sufficient width to admit of the entrance of prey of considerable size, as appears from the circumstance that fishes of some inches in length are occasionally found entire in the stomachs of those medusæ which have a single mouth. The central cavity, which is the stomach of the animal, does not appear to possess any proper coats, but to be simply scooped out of the soft structure of the body. Its form varies in different species; having generally, however, more or less of a star-like shape, composed of four curved rays, which might almost be considered as constituting four stomachs, joined at a common centre. Such, indeed, is the actual structure in the *Medusa aurita*, in which Gaede found the stomach to consist of four spherical sacs, completely separated by partitions. These arched cavities, or sacs, taper as they radiate towards the circumference, and are continued into a canal, from which a great number of other canals proceed; generally, at first, by successive bifurcations of the larger trunks, but afterwards branching off more irregularly, and again uniting by lateral communications so as to compose a complicated net-work of vessels. These ramifications at length unite to form an annular vessel, which encircles the margin of the disk. It appears, also, from the observations of Gaede, that a farther communication is established between this latter vessel, and others which permeate the slender filaments, or tentacula, that hang like a fringe all round the edge of the disk, and which, in the living animal, are in perpetual motion. It is supposed that the elongations and contractions of these filaments are effected by the injection or recession of the fluids contained in those vessels.* Here, then, we see not only a more complex stomach, but also the commencement of a vascular system, taking its rise from that cavity, and calculated to distribute the nutritious juices to every part of the organization.

There are other species of Medusæ, composing the genus *Rhizostoma* of Cuvier, which, instead of having only

* Journal de Physique, lxxxix. 146.

one mouth, are provided with a great number of tubes which serve that office, and which bear a great analogy to the roots of a plant.* The pedicle terminates below in a great number of fringed processes, which, on examination, are found to contain ramified tubes, with orifices opening at the extremity of each process. In this singular tribe of animals there is properly no mouth or central orifice; the only avenues to the stomach being these elongated canals, which collect food from every quarter where they extend, and which, uniting into larger and larger trunks as they proceed towards the body, form one central tube, or œsophagus, terminating in the general cavity of the stomach. The *Medusa pulmo*, of which a figure was given in Vol. I., page 142, belongs to this modern genus, and is now termed the *Rhizostoma Cuvieri*.

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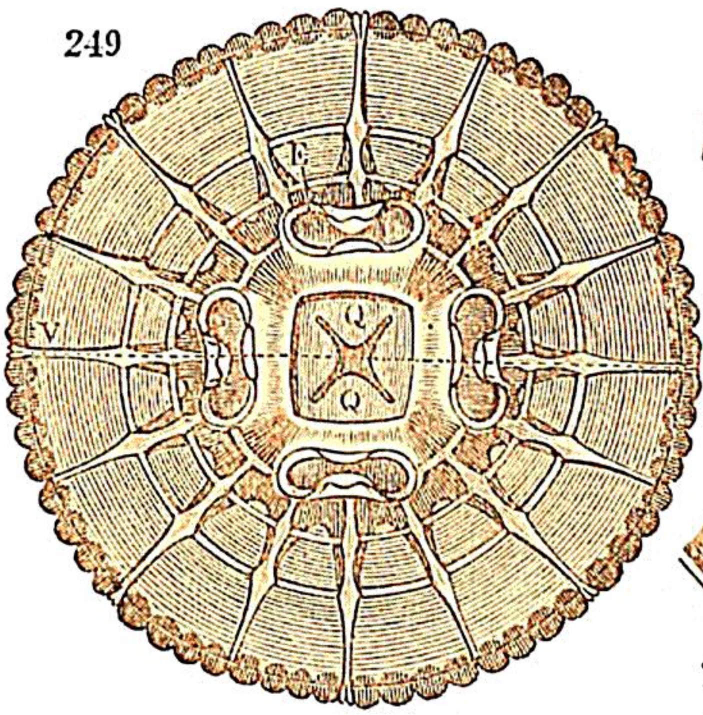

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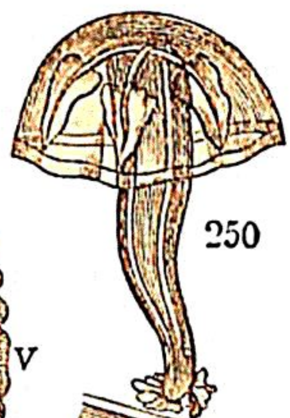

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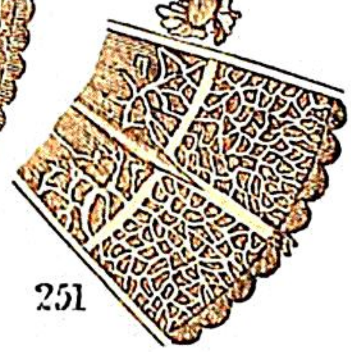

The course of these absorbent vessels is most conveniently traced after they have been filled with a dark coloured liquid. The appearances they present in the *Rhizostoma*

* It is from this circumstance that the genus has received the name it now bears, and which is derived from two Greek words, signifying *root-like mouths*.

Cuvieri, after being thus injected, are represented in the annexed figures; the first of which (Fig. 249,) shows the under surface of that animal, after the pedicle has been removed by a horizontal section, at its origin from the hemispherical body, or *cupola*, as it may be termed, where it has a square prismatic form, so that its section presents the square surface, Q, Q. Fig. 252 is a vertical section of the same specimen; both figures being reduced to about one-half of the natural size. The dotted line, H, H, in the latter figure, shows the plane where the section of the pedicle was made in order to give the view of the base of the hemisphere presented in Fig. 249. On the other hand, the dotted line V, V, in Fig. 249, is that along which the vertical section of the same animal, represented in Fig. 252, was

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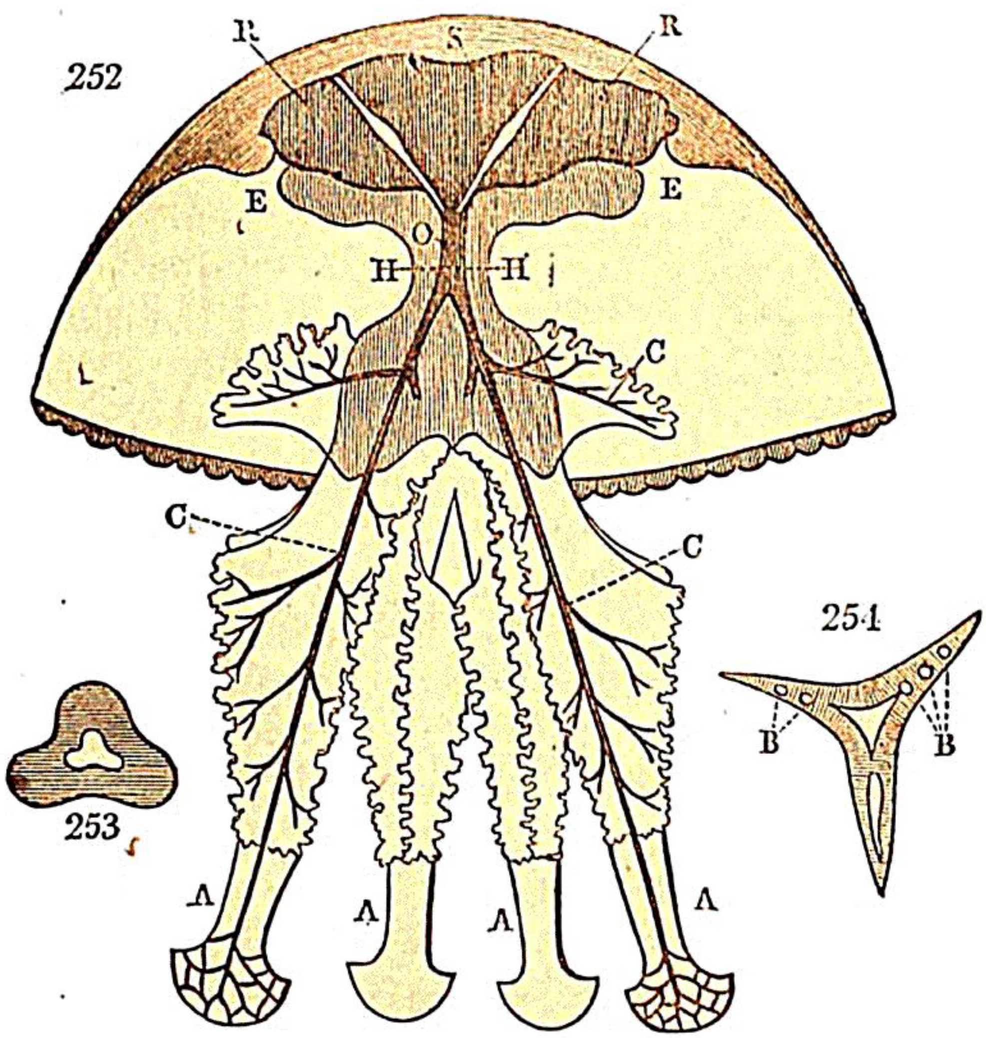

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made; four of the arms (A, A, A, A,) descending from the pedicle being left attached to it. In these arms, or tentacula, may be seen the canals, marked by the dark lines (c, c, c,) which arises from numerous orifices in the extremities and fringed surface of the tentacula, and which, gradually uniting like the roots of a plant, converge towards the centre of the pedicle, and terminate by a common tube, which may be considered as the œsophagus (o,) in one large central cavity, or stomach (s,) situated in the upper part of the cupola. The section of this œsophagus is visible at the centre of Fig. 249, where its cavity has the form of a cross. The stomach has a quadrangular shape, as in the ordinary medusæ; and from each of its four corners there proceed vessels, which are continuous with its cavity, and are distributed by endless ramifications over the substance of the cupola, extending even to the fringed margin, all round its circumference. The mode of their distribution, and their numerous communications by lateral vessels, forming a complete vascular net-work, is seen in Fig. 251, which represents, on a larger scale, a portion of the marginal part of the disk. The two large figures (249 and 252) also show the four lateral cavities (R, R, Fig. 252,) which are contiguous to the stomach, but separated from it by membranous partitions: these cavities have, by some, been supposed to perform an office in the system of the Medusa, corresponding to respiration; an opinion, however, which is founded rather on analogy than on any direct experimental evidence. The entrances into these cavities are seen open at E, in Fig. 249, and at E, E, in the section Fig. 252. A transverse section of one of the arms is given in Fig. 253, showing the form of the absorbent tube in the centre; and a similar section of the extremity of one of the tentacula is seen in Fig. 254, in which, besides the central tube, the cavities of some of the smaller branches (B, B,) which are proceeding to join it, are also visible.

The regular gradation which nature has observed in the complexity of the digestive cavities and other organs, of the various species of this extensive tribe, is exceedingly remarkable: for while some, as the *Eudora*, have, to all appearance, no internal cavity corresponding to a stomach, and are totally unprovided with either pedicle, arms, or tentacula; others, furnished with these latter appendages, are equally destitute of such a cavity; and those belonging to a third family possess a kind of pouch, or false stomach, at the upper part of the pedicle, apparently formed by the mere folding in of the integument. This is the case with the *Geronia*, depicted in Fig. 250, whose structure, in this respect, approaches that of the Hydra, already described, where the stomach consists of an open sac apparently formed by the integuments alone. Thence a regular progression may be followed, through various species, in which the aperture of this pouch is more and more completely closed, and where the tube which enters it branches out into ramifications more or less numerous, as we have seen in the Rhizostoma.* It is difficult to conceive in what mode nutrition is performed in the agastric tribes, or those destitute of any visible stomach; unless we suppose that their nourishment is imbibed by direct absorption from the surface.

Ever since the discovery of the animalcula of infusions, naturalists have been extremely desirous of ascertaining the nature of the organization of these curious beings; but as no mode presented itself of dissecting objects of such extreme minuteness, it was only from the external appearances they present under the microscope that any inferences could be drawn with regard to the existence and form of their internal organs. In most of the larger species, the opaque globules, seen in various parts of the interior, were generally supposed to be either the ova, or the future young, lodged within the body of the parent. In the *Rotifer*, or wheel animalcule of Spallanzani,† a large central organ is plainly perceptible, which was by some imagined to be the heart; but which has been clearly ascertained, by Bonnet, to be a receptacle for food. Muller, and several other observers, have witnessed the larger animalcules devouring the smaller; and the inference was obvious, that, in common with all

* See Péron, Annales du Muséum, xiv. 330.

† Vol. i. p. 58, Fig. 1.

other animals, they also must possess a stomach. But, as no such structure had been rendered visible in the smallest species of infusoria; such as monads, it was too hastily concluded that these species were formed upon a different and a simpler model. Lamark characterised them as being, throughout, of a homogeneous substance, destitute of mouth and digestive cavity, and nourished simply by means of the absorption of particles through the external surface of their bodies.

The nature and functions of these singular beings long remained involved in an obscurity which appeared to be impenetrable; but at length a new light has been thrown on the subject by Professor Ehrenberg, whose researches have recently disclosed fresh scenes of interest and of wonder in microscopic worlds, peopled with hosts of animated beings, almost infinite in number as in minuteness.* In endeavouring to render the digestive organs of the infusoria more conspicuous, he hit upon the fortunate expedient of supplying them with coloured food, which might communicate its tinge to the cavities into which it passed, and exhibit their situation and course. Obvious as this method may appear, it was not till after a labour of ten years that Ehrenberg succeeded in discovering the fittest substances, and in applying them in the manner best suited to exhibit the phenomena satisfactorily. We have already seen that Trembley had adopted the same plan for the elucidation of the structure of the hydra. Gleichen also had made similar attempts with regard to the infusoria; but, in consequence of his having employed metallic or earthy colouring materials,

* The results of Ehrenberg's labours were first communicated to the Berlin Academy; they have since been published in two works in German: the first of which appeared at Berlin in 1830, under the title of "*Organisation, Systematik und Geographisches Verhältniss des Infusionsthierchen.*" The second work appeared in 1832, and is entitled "*Zur Erkenntniss der Organisation in der Richtung des kleinsten Raumes.*" Both are in folio, with plates. An able analysis of the contents of the former of these works, by Dr. Gairdner, is given in The Edenburgh New Philosophical Journal for 1831, p. 201, of which I have availed myself largely in the account which follows.

which acted as poisons, instead of those which might serve as food, he failed in his endeavours. Equally unsuccessful were the trials made by Ehrenberg with the indigo and gum-lac of commerce, which are always contaminated with a certain quantity of white lead, a substance highly deleterious to all animals; but, at length by employing an indigo which was quite pure, he succeeded perfectly.* The moment a minute particle of a highly attenuated solution of this substance is applied to a drop of water in which are some pedunculated vorticellæ, occupying the field of the microscope, the most beautiful phenomena present themselves to the eye. Currents are excited in all directions by the vibrations of the cilia, situated round the mouths of these animalcules, and are readily distinguished by the motions of the minute particles of indigo which are carried along with them; the currents generally all converging towards the orifice of the mouth. Presently the body of the vorticella, which had been hitherto quite transparent, becomes dotted with a number of distinctly circular spots, of a dark blue colour, evidently produced by particles of indigo accumulated in those situations. In some species, particularly those which have a contracted part, or neck, between the head and the body, as the *Rotifer vulgaris*, these particles may be traced in a continuous line in their progress from the mouth through the neck, into the internal cavities.

In this way, by the employment of colouring matters, Ehrenberg succeeded in ascertaining the existence of a system of digestive cavities in all the known genera of this tribe of animals. There is now, therefore, no reason for admitting that cuticular absorption of nutritive matter ever takes place

* The colouring matters proper for these experiments are such as do not chemically combine with water, but yet are capable of being diffused in a state of very minute division. Indigo, sap, green and carmine, answer these conditions, and being also easily recognised under the microscope, are well adapted for these observations. Great care should be taken, however, that the substance employed is free from all admixture of lead, or other metallic impurity.

among this order of beings. Whole generations of these transparent gelatinous animalcules may remain immersed for weeks in an indigo solution, without presenting any coloured points in their tissue, except the circumscribed cavities above described.

Great variety is found to exist in the forms, situations, and arrangement of the organs of digestion in the Infusoria. They differ also in their degree of complication, but without any obvious relation to the magnitude of the animalcule. The *Monas atomus*, the minutest of the whole tribe, exhibits a number of sacs, opening by as many separate orifices, from a circumscribed part of the surface. In others, as in the *Leucophra patula*, of which Fig. 255 represents the appearance under the microscope, there is a long alimentary

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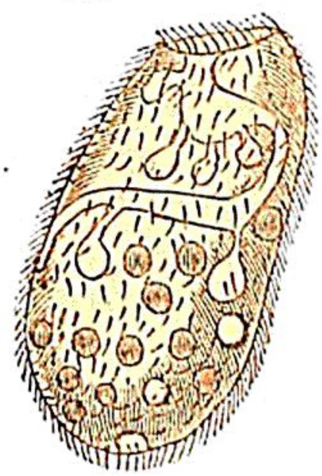

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canal, traversing the greater part of the body, taking several spiral turns, and furnished with a great number of *cæca;* a term which denotes blind pouches, proceeding laterally from any internal canal, and having no other outlet. These cavities become filled with coloured particles immediately after their entrance into the alimentary canal; and must, therefore, be considered as so many stomachs provided for the digestion of the food which they receive.* But they are not all filled at the same time, for some continue long in a

* Ehrenberg terms these *Polygastric infusoria*, from the Greek, signifying *with many stomachs*.

contracted state, so as not to be visible; while, at another time, they readily admit the coloured food. It is, therefore, only by dint of patient watching that the whole extent of the alimentary tube, and its apparatus of stomachs, can be fully made out. Fig. 255, above referred to, exhibits the *Leucophra patula* of Ehrenberg,* with a few of its stomachs filled with the opaque particles; but Fig. 256 shows the whole series of organs as they would appear if they could be taken out of the body, and placed in the same relative situation with the eye of the observer, as they are seen in the first figure. In some species, from one to two hundred of these sacs may be counted, connected with the intestinal tube. Many of the larger species, as the *Hydatina senta*, exhibit a greater concentration of organs, having only a single oval cavity of considerable size, situated in the fore part of the body. In the *Rotifer vulgaris*, the alimentary canal is a slender tube, considerably dilated near its termination. In some *Vorticellæ*, the intestine, from which proceed numerous cœca, makes a complete circular turn, ending close to its commencement: Ehrenberg forms of these the tribe of *Cyclocœla* of which the *Vorticella citrina*, and the *Stentor polymorphus*, are examples. Thus do we discover the same diversity in the structure of the digestive organs of the several races of these diminutive beings, as is found in the other classes of animals.

The *Hydatina senta*, one of the largest of the infusoria, was found by Ehrenberg to possess a highly developed structure with respect to many systems of organs, which we should never have expected to meet with in animals situated so low in the scale. As connected with the nutritive functions, it may here be mentioned that the head of this animalcule is provided with a regular apparatus for mastication, consisting of serrated jaws, each having from two to six teeth. These jaws are seen actively opening and shutting when the animal is taking its food, which consists of

* *Trichoda patula*. Muller.

particles brought within reach of the mouth by means of currents excited by the motions of the cilia:

Such are the simple forms assumed by the organs of assimilation among the lowest orders of the animal creation; namely, digesting cavities, whence proceed various canals, which form a system for the transmission of the prepared nourishment to different parts; but all these cavities and canals being simply hollowed out of the solid substance of the body. As we ascend a step higher in the scale, we find that the stomach and intestinal tube, together with their appendages, are distinct organs, formed by membranes and coats proper to each, and that they are themselves contained in an outer cavity, which surrounds them, and which receives and collects the nutritious juices after their elaboration in these organs. The *Actinia*, or *Sea Anemone*, for example, resembles a polypus in its general form, having a mouth, which is surrounded with tentacula, and which leads into a capacious stomach, or sac, open below, and occupying the greater part of the bulk of the animal; but while, in the polypus, the sides of the stomach constitute also those of the body, the whole being one simple sac; in the actinia, spaces intervene between the coats of the stomach, and the skin of the animal. As the stomach is not a closed sac, but is open below, these cavities are, in fact, continuous with that of the stomach: they are divided by numerous membranous partitions passing vertically between the skin, and the membrane of the stomach, and giving support to that organ. Fig. 257, representing a vertical section of the *Actinia coriacea*, displays this internal structure. B is the base, or disk, by which the animal adheres to rocks: I is the section of the coriaceous integument, showing its thickness: M is the central aperture of the upper surface, which performs the office

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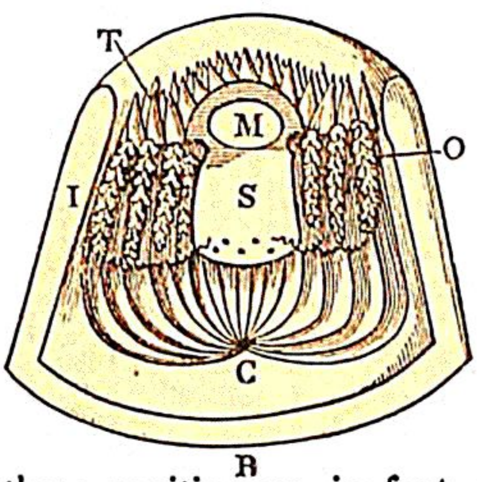
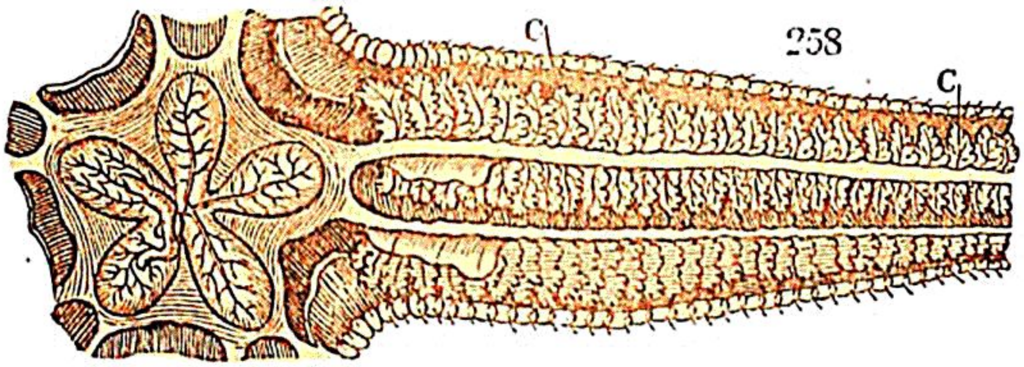


of a mouth, leading to the stomach s, of which the lower orifice is open, and which is suspended in the general cavity, by means of vertical partitions, of which the cut edges are seen below, uniting at a central point, c, and passing between the stomach and the integument. These muscular partitions are connected above with three rows of tentacula, of which the points are seen at r. The ovaries (o) are seen attached to the partition; and the apertures in the lower part of the stomach, by which they communicate with its cavity, may also be perceived.

If we considered the medusa as having four stomachs, we might in like manner regard the *Asterias*, or star-fish, as having ten, or even a greater number. The mouth of this



radiated animal is at the centre of the under surface; it leads into a capacious bag, situated immediately above it, and which is properly the stomach. From this central sac there proceed ten prolongations, or canals, which occupy in pairs the centre of each ray, or division of the body, and subdivide into numerous minute ramifications. These canals, with their branches, are exhibited at c, c, Fig. 258, which represents one of the rays of the Asterias, laid open from the upper side. The canals are supported in their positions by membranes, connecting them with the sides of the cavity in which they are suspended.

In the various species of *Echini*, we find that the alimentary tube has attained a more perfect development; for instead of constituting merely a blind pouch, it passes entirely through the body of the animal. We here find an *œsophagus*, or narrow tube, leading from the mouth to the stomach; and the stomach is continued into a regular intestine, which takes two turns in the cavity of the body, before it terminates.

The alimentary tube in the lower animals frequently exhibits dilatations in different parts: these, if situated in the beginning of the canal, may be considered as a succession of stomachs; while those that occur in the advanced portions are more properly denominated *the great intestine*, by way of distinction from the middle portions of the tube, which are generally narrower, and are termed *the small intestine.* We often see blind pouches, or *cæca*, projecting from different parts of the canal; this is the case with the intestine of the *Aphrodita aculeata*, or sea-mouse. The intestine being generally longer than the body, is obliged to be folded many times within the cavity it occupies, and to take a winding course. In some cases on the other hand, the alimentary tube passes in nearly a straight line through the body, with scarcely any variation in its diameter; this is the case with the *Ascaris*, which is a long cylindric worm; and nearly so with the *Lumbricus terrestris*, or earthworm. In the *Nais*, on the contrary, as shown in Fig. 259, the alimentary tube presents a series of dilatations, which from the transparency of the skin, may be easily seen in the living animal. The food taken in by these worms is observed to be transferred from the one to the other of its numerous stomachs, backwards and forwards many times before its digestion is accomplished.

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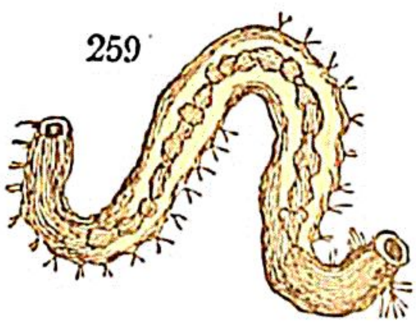

The stomach of the *Leech* is very peculiar in its structure: its form, when dissected off, and removed from the body, is shown in Fig. 260. It is of great capacity, occupying the larger part of the interior of the body; and its cavity is expanded by folds of its internal membrane into several pouches (c, c, c.) Mr. Newport, who has lately examined its structure with great care, finds that each of the

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ten portions into which it is divided, sends out, on the part most remote from the œsophagus (O,) two lateral pouches, or cæca; which, as they are traced along the canal, become both wider and longer, so that the tenth pair of cæca (A) extends to the hinder extremity of the animal; the intestine (I,) which is very short, lying between them.* It has long been known, that if, after the leech has fastened on the skin, a portion of the tail be cut off, the animal will continue to suck blood for an indefinite time: this arises from the circumstances, that the cæcal portions of the stomach are laid open, so that the blood received into that cavity flows out as fast as it is swallowed.

A structure very similar to that of the leech is met with in the digestive organs of the *Glossopora tuberculata*, (Hirudo complanata, Linn.) of which Fig. 263 represents a magnified view from the upper side. When seen from the under side, as is shown in Fig. 264, the cavity of the stomach is distinctly seen, prolonged into several cells, divided by partitions, and directed towards the tail. The two last of these cells (C C)

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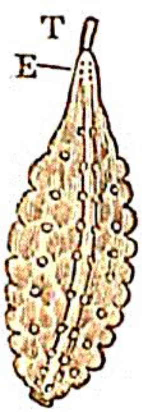

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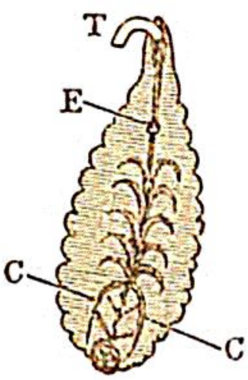

* This figure was engraved from a drawing made, at my request, by Mr. Newport, from a specimen which he dissected, and which he was so obliging as to show me. Fig. 261 represents the mouth, within which are seen the three teeth; and Fig. 262, one of the teeth detached. A paper, descriptive of the structure of the stomach of the leech, by Mr. Newport, was lately read

are much longer than the rest, and terminate in two blind sacs, between which is situated a tortuous intestinal tube.*

at a meeting of the Royal Society. See the abstracts of the proceedings of the Society, for June, 1833.

* In both these figures, T is the tubular tongue, projected from the mouth. In Fig. 263, E are the six eyes, situated on the extremity which corresponds to the head; and a double longitudinal row of white tubercles is also visible, extending along the back of the animal. E, in Fig. 264, is the entrance into a cavity, or pouch, provided for the reception of the young. See Johnson, Phil. Trans. for 1817, p. 343.

CHAPTER V.

Nutrition in the higher orders of Animals.

In proportion as we rise in the animal scale, we find that the operations of Nutrition become still farther multiplied, and that the organs which perform them are more numerous and more complicated in their structure. The long series of processes requisite for the perfect elaboration of nutriment, is divided into different stages; each process is the work of a separate apparatus, and requires the influence of different agents. We no longer find that extreme simplicity which we noticed as so remarkable in the hydra and the medusa, where the same cavity performs, at once, the functions of the stomach and of the heart. The manufacture of nutriment, if we may so express it, is, in these lower zoophytes, conducted upon a small scale, by less refined methods, and with the strictest economy of means: the apparatus is the simplest, the agents the fewest possible, and many different operations are carried on in one and the same place.

As we follow the extention of the plan in more elevated stages of organic development, we find a farther division of labour introduced. Of this we have already seen the commencement in the multiplication of the digesting cavities of the *Leech* and other Annélida; but, in animals which occupy a still higher rank, we observe a more complete separation of offices, and a still greater complication of organs. The principle of the division of labour being carried to a much greater extent than in the inferior departments of the animal creation. Besides the stomach, or receptacle for the unassimilated food, another organ, the heart, is provided for the uniform distribution of the nutritious fluids elaborated by the organs of digestion. This separation of functions, again, leads to the introduction of another system of canals or vessels, for transmitting the fluids from the organs which prepare them to the heart, as into a general reservoir. In the higher orders of the animal kingdom, all these processes are again subdivided and varied, according to the species of food, the habits and mode of life, assigned by nature to each individual species. For the purpose of conveying clearer notions of the arrangement of this extensive system of vital organs, I have drawn the annexed plan (Fig. 265,) which

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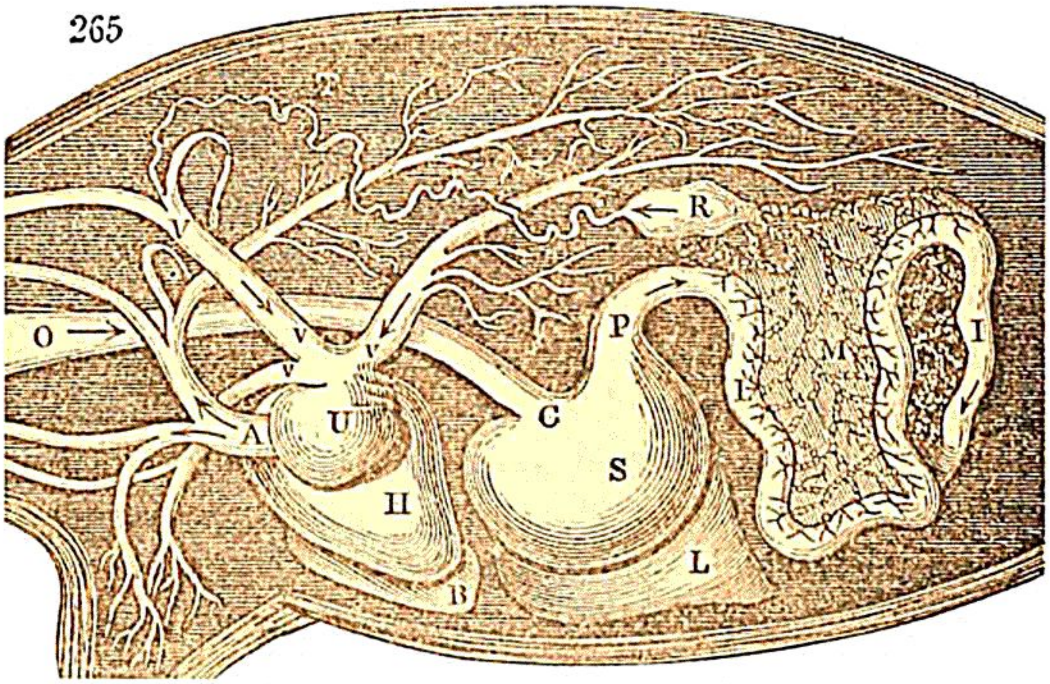

exhibits them in their natural order of connexion, and as they might be supposed to appear in a side view of the interior of a quadruped. To this diagram I shall make frequent reference in the following description of this system.

The food is, in the first place, prepared for digestion by several mechanical operations, which loosen its texture and destroy its cohesion. It is torn asunder and broken down by the action of the jaws and of the teeth; and it is, at the same time, softened by an admixture with the fluid secretions of the mouth. It is then collected into a mass, by the action of the muscles of the cheek and tongue, and swallowed by the regulated contractions of the different parts of the throat. It now passes along a muscular tube, called the *Œsophagus,* (represented in the diagram by the letter O,) into the stomach, (S,) of which the entrance (C) is called the *cardia.*

In the stomach the food is made to undergo various chemical changes; after which it is conducted through the aperture termed the *pylorus* (P,) into the canal of the intestine (I I,) where it is farther subjected to the action of several fluid secretions derived from large glandular organs situated in the neighbourhood, as the liver (L) and the pancreas; and elaborated into the fluid which is termed *Chyle.*

The Chyle is taken up by a particular set of vessels, called the *Lacteals,* which transmit it to the heart (H.) These vessels are exceedingly numerous, and arise by open orifices from the inner surface of the intestines, whence they absorb, or drink up the chyle. They may be compared to internal roots, which unite as they ascend along the *mesentery* (M,) or membrane connecting the intestines with the back forming larger and larger trunks, till they terminate in an intermediate reservoir (R,) which has been named the *Receptacle of the Chyle.* From this receptacle there proceeds a tube, which from its passing through the thorax, is called *the Thoracic duct* (T;) it ascends along the side of the spine, which protects it from compression, and opens at V, into the large veins which are pouring their contents into the *auricle*, or first cavity of the heart (U,) whence it immediately passes into the *ventricle,* or second cavity of that organ (H.) Such in the more perfect animals, is the circuitous and guarded route, which every particle of nourishment must take before it can be added to the general mass of circulating fluid.

By its admixture with the blood already contained in these vessels, and its purification by the action of the air in the respiratory organs (B,) the chyle becomes assimilated, and is distributed by the heart through appropriate channels of circulation called *arteries* (of which the common trunk, or *Aorta*, is seen at A,) to every part of the system; thence returning by the *veins* (V, *v*, *v*,) to the heart. The various modes in which these functions are conducted in the several tribes of animals will be described hereafter. It will be sufficient for our present purpose to state, by way of completing the outline of this class of functions, that, like the returning sap of plants, the blood is made to undergo farther modifications in the minute vessels through which it circulates; new arrangements of its elements take place during its passage through the subtle organization of the glands, which no microscope has yet unravelled: new products are here formed, and new properties acquired, adapted to the respective purposes which they are to serve in the animal economy. The whole is one vast Laboratory, where mechanism is subservient to Chemistry, where Chemistry is the agent of the higher powers of Vitality, and where these powers themselves minister to the more exalted faculties of Sensation and of Intellect.

The digestive functions of animals, however complex and varied, and however exquisitely contrived to answer their particular objects, yet afford less favourable opportunities of tracing distinctly the adaptation of means to the respective ends, than the mechanical functions. This arises from the circumstance that the processes they effect imply a refined chemistry, of which we have as yet but a very imperfect knowledge; and that we are also ignorant of the nature of the vital agents concerned in producing each of the chemical changes which the food must necessarily undergo during its assimilation. We only know that all these changes are slowly and gradually effected; the materials having to pass through a great number of intermediate stages before they can attain their final state of elaboration.

Hence, whenever we can ascertain the degrees of difference existing between the chemical condition of the substance taken into the body, and that of the product derived from it, we are furnished with a kind of scale whereby we may estimate the length of the process required, and the amount of power necessary for its conversion into that product. It is obvious, for example, that the chemical changes which vegetable food must be made to undergo, in order to assimilate it to blood, must be considerably greater than those required to convert animal food into the same fluid, because the latter is itself derived, with only slight modification, immediately from the blood. We accordingly find it to be an established rule, that the digestive organs of animals which feed on vegetable materials are remarkable for their size, their length, and their complication, when compared with those of carnivorous animals of the same class. This rule applies, indeed, universally to Mammalia, Birds, Reptiles, Fishes, and also to Insects: and below these we can scarcely draw the comparison, because nearly all the inferior tribes subsist wholly upon animal substances. Many of these latter animals have organs capable of extracting nourishment from substances which we should hardly imagine contained any sensible portion. Thus, on examining the stomach of the earth-worm, we find it always filled with moist earth, which is devoured in large quantities, for the sake of the minute portion of vegetable and animal materials that happen to be intermixed with the soil; and this slender nutriment is sufficient for the subsistence of that animal. Many marine worms, in like manner, feed apparently upon sand alone; but that sand is generally intermixed with fragments of shells, which have been pulverized by the continual rolling of the tide and the surge; and the animal matter contained in these fragments, affords them a supply of nutriment adequate to their wants. It is evident, that when, as in the preceding instances, large quantities of indigestible materials are taken in along with such as are nutritious, the stomach and other digestive cavities must be rendered more than usually capacious. It is obvious also that the structure of the digestive organs must bear a relation to the mechanical texture, as well as to the chemical qualities of the food; and this we find to be the case in a variety of instances, which will hereafter be specified.

The activity of the digestive functions, and the structure of the organs, will also be regulated by a great variety of other circumstances in the condition of the animal, independent of the mechanical or chemical nature of the food. The greater the energy with which the more peculiarly animal functions of sensation and muscular action are exercised, the greater must be the demand for nourishment, in order to supply the expenditure of vital force created by these exertions. Compared with the torpid and sluggish reptile, the active and vivacious bird or quadruped requires and consumes a much larger quantity of nutriment. The tortoise, the turtle, the toad, the frog, and the chameleon, will, indeed, live for months without taking any food. Fishes, which, like reptiles, are cold-blooded animals, although at all times exceedingly voracious when supplied with food, can yet endure long fasts with impunity.

The rapidity of development has also great influence on the quantity of food which an animal requires. Thus, the caterpillar, which grows very quickly, and must repeatedly throw off its integuments, during its continuance in the larva state, consumes a vast quantity of food compared with the size of its body; and hence we find it provided with a digestive apparatus of considerable size.

CHAPTER VI.

PREPARATION OF FOOD.

§ 1. *Prehension of Liquid Food.*

In studying the series of processes which constitute assimilation, our attention is first to be directed to the mode in which the food is introduced into the body, and to the mechanical changes it is made to undergo before it is subjected to the chemical action of the digestive organs. The nature of these preliminary processes will of course, vary according to the texture and mechanical condition of the food. Where it is already in a fluid state, mastication is unnecessary, and the receiving organs consist simply of an apparatus for suction. This is the case very generally with the *Entozoa*, which subsist upon the juices of other animals, and which are all provided with one or more sucking orifices, often extended in the form of a tube or proboscis.* The *Hydatid*, for instance, has four sucking apertures disposed round the head of the animal: the *Tænia* has orifices of this kind in each of its jointed segments: the *Ascaris* and the *Earth-worm* have each a simple mouth. The margin of the mouth is often divided, so as to compose lips; of these there are generally two, and in the leech there are three. In some rare cases, as in the *Planaria*, there is, besides the

* Some species of *Fasciolæ*, or flukes, are furnished with two, three, six, or more sucking disks, by which they adhere to surfaces: to these animals the names *Distoma*, *Tristoma*, *Hexastoma*, and *Polystoma* have been given; but these denominations, implying a plurality of mouths, are evidently incorrect, since the sucking disks are not perforated, and do not perform the office of mouths; and the true mouth for the reception of food is single. Cuvier discovered an animal of this class furnished with above a hundred of these cup-shaped sucking organs. See Edinburgh Philos. Journal, xx. 101.

ordinary mouth, a tube also provided for suction, in a different part of the body, but leading into the same stomach.*

When the instrument for suction extends for some length from the mouth, it is generally termed a *proboscis:* such is the apparatus of the butterfly, the moth, the gnat, the house fly, and other insects that subsist on fluid aliment. The proboscis of the *Lepidoptera*, (Fig. 266,) is a double tube, con-

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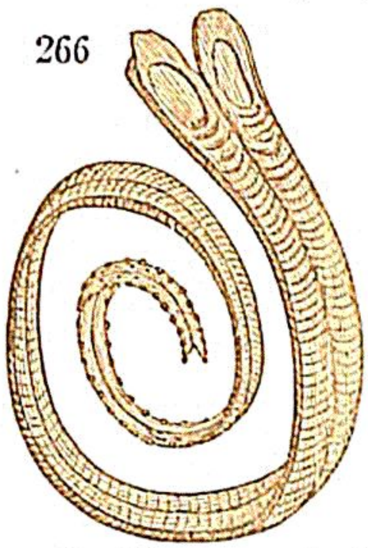

structed by the two edges being rolled longitudinally till they meet in the middle of the lower surface, thus forming a tube on each side, but leaving also another tube, intermediate to the two lateral ones. This middle tube is formed by the junction, of two grooves, which, by the aid of a curious apparatus of hooks, resembling those of the laminæ of a feather already described,† lock into each other, and can be either united into an air tight canal, or be instantly separated at the pleasure of the animal. Reaumur conceives that the lateral tubes are intended for the reception of air, while the central canal conveys the honey, which the insect sucks from flowers, by suddenly unrolling the spiral coil, into which the proboscis is usually folded, and darting it into the nectary.‡

In the *Hemiptera*, the proboscis is a tube, either straight or jointed, guarded by a sheath, and acting like a pump. The *Diptera* have a more complicated instrument for suction, consisting of a tube, of which the sides are strong and fleshy, and moveable in every direction, like the trunk of an elephant; it has at its extremity a double fold, resembling lips, which are well adapted for suction. The gnat, and other insects which pierce the skin of animals, have, for this purpose, instruments, termed, from their shape and office,

* Phil. Trans. for 1822, 442.

† Volume i. p. 393.

‡ Kirby and Spence's Entomology, vol. ii. p. 390.

*lancets.** In the *Gnat*, they are five or six in number, finer than a hair, exceedingly sharp, and generally barbed on one side. In the *Tabanus*, or horse-fly, they are flat like the blade of a knife. These instruments are sometimes constructed so as to form, by their union, a tube adapted for suction. In the flesh-fly, the proboscis is folded like the letter Z, the upper angle pointing to the breast, and the lower one to the mouth. In other flies there is a single fold only.

Those insects of the order *Hymenoptera*, which, like the bee, suck the honey of flowers, have, together with regular jaws, a proboscis formed by the prolongation of the lower lip, which is folded so as to constitute a tube: this tube is protected by the mandibles, and is projected forwards by being carried on a pedicle, which can be folded back when the tube is not in use. The mouths of the *Acephalous Mollusca* are merely sucking apertures, with folds like lips, and without either jaws, tongue, or teeth, but having often tentacula arising from their margins.

Among fishes, we meet with the family of *Cyclostomata*, so called from their having a circular mouth, formed for suction. The margin of this mouth is supported by a ring of cartilage, and is furnished with appropriate muscles for producing adhesion to the surfaces to which it is applied; the mechanism and mode of its attachment being similar to that of the leech. To this family belong the *Myxine* and the *Lamprey*. So great is the force of adhesion exerted by this sucking apparatus, that a lamprey has been raised out of the water with a stone, weighing ten or twelve pounds, adhering to its mouth.

Humming birds have a long and slender tongue, which can assume the tubular form, like that of the butterfly or the bee, and for a similar purpose, namely, sucking the juices of flowers. Among the mammalia, the *Vampire Bat* affords another instance of suction by means of the tongue, which

* Kirby and Spence's Entomology, vol. iii. p. 467.

is folded into a tubular shape for that purpose. But suction among the mammalia is generally performed by the muscles of the lips and cheeks, aided by the movements of the tongue, which, when withdrawn to the back of the cavity, acts like the piston of a pump. In the lamprey, this hydraulic action of the tongue is particularly remarkable. Many quadrupeds, however, drink by repeatedly dipping their tongue into the fluid, and quickly drawing it into the mouth.

§ 2. *Prehension of Solid Food.*

When the food consists of solid substances, organs must be provided; first, for their prehension and introduction into the mouth; secondly, for their detention when so introduced; and thirdly, for their mechanical division into smaller fragments.

Of those instruments of prehension which are not portions of the mouth itself, and which form a series of variously constructed organs extending from the tentacula of the polypus to the proboscis of the elephant, and to the human arm and hand, some account has already been given in the history of the mechanical functions; but, in a great number of instances, prehension is performed by the mouth, or the parts which are extended from it, and may be considered as its appendices. The prehensile power of the mouth is derived principally from the mechanical form and action of the jaws, which open to receive, and close to detain the bodies intended as food; and to this latter purpose, the teeth, when the mouth is furnished with them, likewise materially contribute, although their primary and more usual office is the mechanical division of the food, by means of mastication, an action in which the jaws, in their turn, co-operate. Another principal purpose effected by the jaws is that of giving mechanical power to the muscles, which, by acting upon the sides of the cavity of the mouth, tend to compress and propel the contained food. We find, accordingly, that all animals of a highly developed structure are provided with jaws.

Among the animals which are ranked in the class of Zoophytes, the highest degrees of development are exhibited by the Echinodermata, and in them we find a remarkable perfection in the organs of mastication. The mouth of the *Echinus* is surrounded by a frame-work of shell, consisting of five converging pieces, each armed with a long tooth; and for the movement of each part there are provided separate muscles, of which the anatomy has been minutely described by Cuvier. In the shells of the echini which are cast on the shore, this calcareous frame is usually found entire in the inside of the outer case; and Aristotle having noticed its resemblance to a lantern, it has often gone by the whimsical name of the *lantern of Aristotle*.

In all articulated animals which subsist on solid aliment, the apparatus for the prehension and mastication of the food, situated in the mouth, is exceedingly complicated, and admits of great diversity in the different tribes; and, indeed, the number and variety of the parts of which it consists is so great, as hardly to admit of being comprehended in any general description. In most insects, also, their minuteness is an additional obstacle to the accurate observation of their anatomy, and of the mechanism of their action. The researches, however, of Savigny,* and other modern entomologists, have gone far to prove, that, amidst the infinite variations observable in the form and arrangement of the several parts of these organs, there is still preserved, in the general plan of their construction, a degree of uniformity quite as great as that which has been remarked in the fabric of the vertebrated classes. Not only may we recognise, in every instance, the same elements of structure, but we may also trace regular chains of gradation, connecting forms ap-

* See his "Théorie des Organes de la bouche des Animaux invertébrés et articulés," which forms the first part of the "Mémoires sur les Animaux sans vertèbres." Paris, 1816.

parently most remote, and organs destined for widely different uses: so that even when there has been a complete change of purpose, we still perceive the same design followed, the same model copied, and the same uniformity of plan preserved in the construction of the organs of every kind of mastication; and there prevails in them the same unity of system as is displayed in so marked a manner in the conformation of the organs of progressive motion. The jaws, which, in one tribe of insects, are formed for breaking down and grinding the harder kinds of food, are, in another, fitted for tearing asunder the more tough and fibrous textures; they are fashioned, in a third, into instruments for taking up the semi-fluid honey prepared by flowers; while, again, in a fourth, they are prolonged and folded into a tubular proboscis, capable of suction, and adapted to the drinking of fluid aliment. Pursuing the examination of these organs in another series of articulated animals, we find them gradually assuming the characters, as well as the uses, of instruments of prehension, of weapons for warfare, of pillars for support, of levers for motion, or of limbs for quick progression. Some of these remarkable metamorphoses of organs have already attracted our attention, in a former part of this treatise.* Jaws pass into feet, and feet into jaws, through every intermediate form; and the same individual often exhibits several steps of these transitions; and is sometimes provided also with supernumerary organs of each description. In the Arachnida, in particular, we frequently meet with supernumerary jaws, together with various appendices, which present remarkable analogies of form with the antennæ, and the legs and feet of the Crustacea.

The principal elementary parts which enter into the composition of the mouth of an insect, when in its most perfect state of development, are the seven following: a pair of upper jaws, a pair of lower jaws, an upper and a lower lip, and a tongue.† These parts in the *Locusta viridissima*, or com-

* Vol. i. p. 206.

† All these parts, taken together, were termed by Fabricius *instrumenta*

mon grasshopper, are delineated in their relative situations, but detached from one another, in Fig. 267. The upper jaws, (M,) which are termed the *mandibles*, are those prin-

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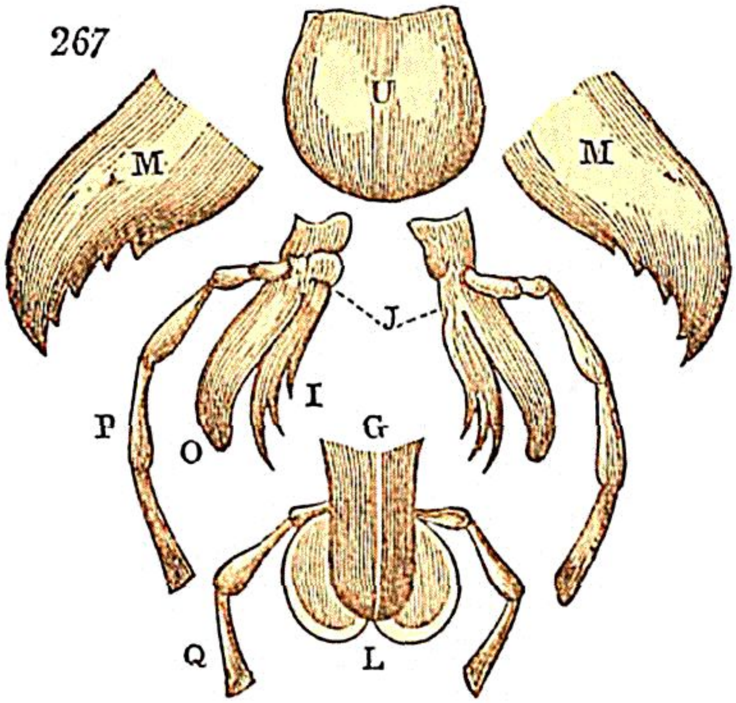


cipally employed for the mastication of hard substances; they are, accordingly, of greater strength than the lower jaws, and their edges are generally deeply serrated, so as to act like teeth in dividing and bruising the food. Some of these teeth are pointed, others wedge-shaped, and others broad, like grinders; their form being, in each particular case, adapted to the mechanical texture of the substances to which they are designed to be applied. Thus, the mandibles of some *Melolonthæ* have a projection, rendered rough by numerous deep transverse furrows, converting it into a file for wearing down the dry leaves, which are their natural food.* In most cases, indeed, we are, in like manner, enabled, from a simple inspection of the shape of the teeth, to

cibaria; and upon their varieties of structure he founded his celebrated system of entomological classification. Kirby and Spence have denominated them *trophi*. See their introduction to Entomology, vol. iii. p. 417. To the seven elements above enumerated, Savigny adds, in the *Hemiptera*, an eighth, which he terms the *Epiglossa*.

* Knoch, quoted by Kirby

form tolerably accurate ideas of the kind of food on which the insect naturally subsists.*

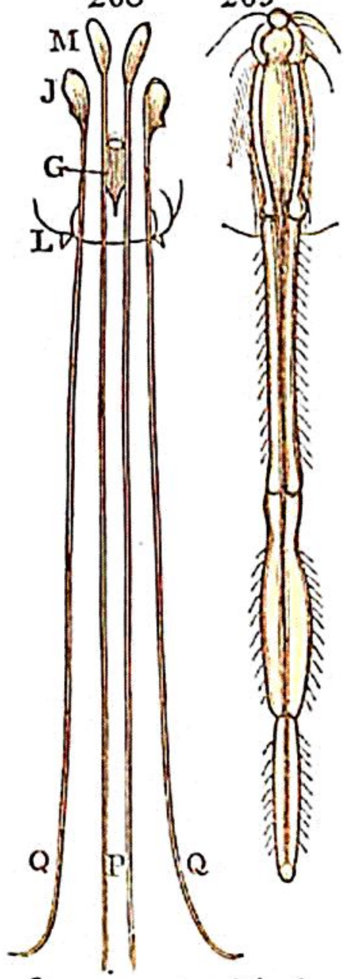
Above, or rather in front of the mandibles, is situated the *labrum*, or upper lip (U.) It is usually of a hard or horny texture, and admits of some degree of motion; but its form and direction are exceedingly various in different tribes of insects. The lower pair of jaws (J,) or *maxillæ*, as they have been termed, are behind the mandibles, and between them is situated the *labium*, or lower lip (L,) which closes the mouth below, as the *labrum* does above. In the grasshopper, each maxilla consists of an outer and an inner plate (O and I.) The jaws of insects are confined, by their articulations with the head, to motions in a horizontal plane only, so that they open and close by lateral movements, and not upwards and downwards, as is the case with the jaws of vertebrated animals. The maxillæ are, in most cases, employed principally for holding the substances on which the dividing or grinding apparatus of the mandibles is exerted. A similar use may be assigned also to the organs denominated *Palpi*, or *Antennulæ* (P, Q,) which are jointed filaments, or processes, attached to different parts of the mouth, and most usually to the maxillæ and the labium; the former (P) being termed the *maxillary*, and the latter (Q) the *labial palpi*. In addition to these parts, another, which, from its supposed use, has been denominated *Glossa*, or tongue (G,) is also generally found.

For an account of the various modifications which these parts receive in different tribes and species, I must refer to works which treat professedly of this branch of comparative anatomy. I shall content myself with giving a single example of the conversion of structure here alluded to, in that of the *rostrum*, or proboscis of the *Cimex nigricornis*. This insect belongs to the order Hemiptera, which has been usually characterized as being destitute of both mandibles

* See a memoir by Marcel des Serres, in the Annales du Muséum d'Hist. Nat. xiv. 56.

and jaws, and as having, instead of these parts, an apparatus of very different construction, designed to pierce the skin of animals, and suck their juices. But Savigny, on applying the principles of his theory, has recognised, in the proboscis of the Cimex, the existence of all the constituent elements which are found in the mouth of insects formed for the mastication of solid food. This proboscis consists of four elongated filaments, contained in a kind of sheath: the filaments are represented in Fig. 268, separated to a little distance from each other, in order that their respective origins may be distinctly seen; the one set (Q) being prolongations of the mandibles (J,) and the other set (P,) being, in like manner, prolongations of the maxillæ (M.) Between these filaments, and near their commencement, is seen a pointed cartilaginous body (G,) which is the glossa, or tongue; and the aperture seen at its root is the passage into the œsophagus. The sheath is merely the elongated labium, of which the base is seen at L, in Fig. 268; but is represented, in its whole length, in Fig. 269, where the groove for containing the filaments above described, is apparent.

268 269



In the mouths of the Annelida we often meet with hard bodies, which serve the purposes of jaws and of teeth. The retractile proboscis of the *Aphrodite*, or sea-mouse, is furnished with four teeth of this description. The Leech has, immediately within its lips, three semi-circular teeth, with round and sharp cutting edges: they are delineated in Fig. 261, in their relative position; and Fig. 262 represents one of the teeth detached from the rest. It is with these teeth that the leech pierces the skin of the animals whose blood it sucks; and, as soon as the wound is inflicted, the teeth, being moveable at their base, fall back, leaving the opening of the mouth free for sucking. The wound thus made is of a peculiar form, being composed of three lines, radiating from a centre, where the three teeth had penetrated.

Most of the Mollusca which inhabit univalve shells are provided with a tubular organ, of a cylindric or conical shape, capable of elongation and contraction, by circular and longitudinal muscular fibres, and serving the purpose of a proboscis, or organ of prehension, for seizing and conveying food into the mouth. These tubes are of great size in the *Buccinum*, the *Murex*, and the *Voluta*, as also in the *Doris*, which, though it has no shell, is likewise a gasteropode. In those mollusca of this order which have not a proboscis, as the *Limax*, or slug, the *Helix*, or snail, and the *Aplysia*, or sea-hare, the mouth is furnished with broad lips, and is supported by an internal cartilage, having several tooth-like projections, which assist in laying hold of the substances taken as food. That of the snail is represented in Fig. 270.

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All the *Sepiæ*, or cuttle fish tribe, are furnished, at the entrance of the mouth, with two horny jaws, having a remarkable resemblance to the bill of a parrot; excepting that the lower piece is the larger of the two, and covers the upper one, which is the reverse of what takes place in the parrot. These constitute a powerful instrument for breaking the shells of the mollusca and crustacea, which compose the usual prey of these animals.

Fishes almost always swallow their food entire, so that their jaws and teeth are employed principally as organs of prehension and detention; and the upper jaw, as well as the lower one, being moveable upon the cranium, they are capable of opening to a great width. The bony pieces which compose the jaws are more numerous than the corresponding bones in the higher classes of vertebrata, and they appear, therefore, as if their development had not proceeded, sufficiently far to effect their consolidation into more compact structures.*

Fishes which live upon other animals of the same class having a soft texture, are furnished with teeth constructed merely for seizing their prey, and perhaps also for slightly dividing it, so as to adapt it to being swallowed. These teeth are of various shapes, though usually sharp at the points, and either conical or hooked at the extremity, with the points always directed backwards, in order to prevent the escape of the animal which has been seized. Fishes which subsist on testaceous mollusca have teeth with grinding surfaces, and their jaws are also adapted for mastication. Every part of the mouth, tongue, and even throat, may afford lodgement for teeth in this class of animals. Almost the whole cavity of the mouth of the *Anarrhichas lupus*, or wolf-fish, may be said to be paved with teeth, a triple row being implanted on each side; so that this fish exerts great power in breaking shells. The *Shark* has numerous rows of sharp teeth, with serrated margins: these, at first sight, appear to be formidable instruments; but as the teeth in the opposite jaws do not meet, it is evident that they are not intended for cutting, like the incisors of mammalia.

Among Reptiles we find the Batrachia almost wholly destitute of teeth. *Frogs*, indeed, exhibit two rows of very fine points; the one in the upper jaw, and the other passing transversely across the palate; they may be considered as teeth existing in a rudimental state; for whatever may be their uses, they are not sufficiently developed to be useful in mastication. There are about forty of these minute teeth on each side in the frog. In the Salamander, there are sixty above and below; and also thirty on each side of the palate.

The tongue of the frog is of great length; its root is attached close to the fore part of the lower jaw, while its point,

* Attempts have been made to trace analogies between the different segments of the jaws of fishes and corresponding parts of the mouths of crustacea and of insects; but the justness of these analogies is yet far from being satisfactorily proved.

which is cloven, is turned backwards, extending into the throat and acting like a valve in closing the air passage into the lungs. If, when this animal has approached within a certain distance of the insect it is about to seize, we watch it with attention, we are surprised to observe the insect suddenly disappear, without our being able to perceive what has become of it. This arises from the frog having darted out its tongue upon its victim with such extreme quickness, and withdrawn it with the insect adhering to it, so rapidly, that it is scarcely possible for the eye to follow it in its motion. The *Chameleon* also has a very long and slender tongue, the extremity of which is dilated into a kind of club or spoon, and covered with a glutinous matter: with this instrument the animal catches insects from a considerable distance, by a similar manœuvre to that practised by the frog.*

As Serpents swallow their prey entire, so the bones of their jaws and face are formed to admit of great expansion, and freedom of motion upon one another. Serpents and Lizards have generally curved or conical teeth, calculated rather for tearing and holding the food, than for masticating it: like those of fishes, they are affixed partly to the jaws, and partly to the palate. The Chelonian reptiles have no teeth, their office being supplied by the sharp cutting edges of the horny portion of the jaws.

Birds as well as serpents have a moveable upper jaw; but they are also provided with beaks of various forms, in which we may trace an exact adaptation to the kind of food appropriated to each tribe; thus, predaceous birds, as the eagle and the hawk tribe, have an exceedingly strong hooked beak, for tearing and dividing the flesh of the animals on which they prey; while those that feed on insects, or on grain, have pointed bills, adapted to picking up minute objects. Aquatic birds have generally flattened bills, by which they

* Mr. Houston has given a description of the structure of this organ, and of the muscles by which it is moved, in a paper contained in the Transactions of the Royal Irish Academy, vol. xv. p. 177.

can best select their food among the sand, the mud, or the weeds at the bottom of the water; and their edges are frequently serrated, to allow the fluid to filter through, while the solid portions are retained in the mouth. The duck affords an instance of this structure; which is, however, still more strongly marked in the genus *Mergus*, or Mergansor, where the whole length of the margin of the bill is beset with small sharp pointed teeth, directed backwards: they are particularly conspicuous in the *Mergus serrator*, or red-breasted Mergansor. The object of the barbs and fringed processes which are appended to the tongue in many birds, such as that of the *Toucan* and the *Parrakeet*, appears in like manner, to be the detention of substances introduced into the mouth.

The beak of the *Hæmatopus*, or Oyster-catcher, has a wedge shape, and acts like an oyster-knife for opening bivalve shells.

In the *Loxia curvirostra*, or Cross-bill, the upper and lower mandibles cross each other when the mouth is closed, a structure which enables this bird to tear open the cones of the pine and fir, and pick out the seeds, by insinuating the bill between the scales. It can split cherry stones with the utmost ease, and in a very short time, by means of this peculiarly shaped bill.*

Birds which dive for the purpose of catching fish have often a bill of considerable length, which enables them to secure their prey, and change its position till it is adapted for swallowing.

The *Rhynchops*, or black Skimmer, has a very singularly formed beak; it is very slender, but the lower mandible very much exceeds in length the upper one, so that while skimming the waves in its flight, it cuts the water like a plough-share, catching the prey which is on the surface of the sea.

The *Woodpecker* is furnished with a singular apparatus for enabling it to dart out with great velocity its long and

* See a paper on the mechanism of the bill of this bird, by Mr. Yarrell, in the Zoological Journal, iv. 459.

pointed tongue, and transfix the insects on which it principally feeds; and these motions are performed so quickly that the eye can scarcely follow them. This remarkable mechanism is delineated in Fig. 271, which represents the head of the woodpecker, with the skin removed and the parts dissected. The tongue itself (T) is a slender sharp-pointed horny cylinder, having its extremity (B) beset with barbs, of which the points are directed backwards: it is supported on a slender *Os Hyoides*, or lingual bone, to the posterior end of which the extremities of two very long and narrow cartilaginous processes are articulated.* The one on the right side is shown in the figure, nearly in the whole

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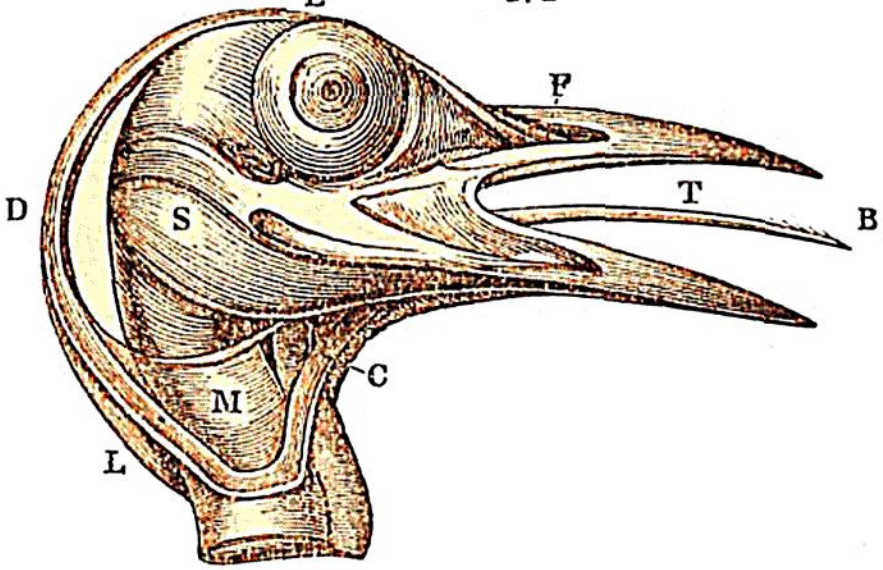

extent of its course, at C, D, E, F, and a small portion of the left cartilage is seen at L. The two cartilages form, at their junction with the tongue, a very acute angle, slightly diverging as they proceed backwards; until, bending downwards (at C,) they pass obliquely round the sides of the neck, connected by a membrane (M;) then, being again inflected upwards, they converge towards the back of the head, where they meet, and, being enclosed in a common sheath, are conducted together along a groove, which extends forwards, along the middle line of the cranium (E,) till it arrives between the eyes. From this point, the groove,

* These cartilages correspond in situation, at the part, at least, where they are joined to the os hyoides, to what are called the *cornua*, or horns of that bone, in other animals.

and the two cartilages it contains, which are now more closely conjoined, are deflected towards the right side, and terminate at the edge of the aperture of the right nostril (F,) into which the united cartilages are finally inserted. In order that their course may be seen more distinctly, these cartilages are represented in the figure (at D,) drawn out of the groove provided to receive and protect them.* A long and slender muscle is attached to the inner margin of each of these cartilages, and their actions conspire to raise the lower and most bent parts of the cartilages, so that their curvature is diminished, and the tongue protruded to a considerable distance, for the purpose of catching insects. As soon as this has been accomplished, these muscles being suddenly relaxed, another set of fibres, passing in front of the anterior portion of the cartilages nearly parallel to them, are thrown into action, and as suddenly retract the tongue into the mouth, with the insect adhering to its barbed extremity. This muscular effort is, however, very materially assisted by the long and tortuous course of these arched cartilages, which are nearly as elastic as steel springs, and effect a considerable saving of muscular power.† This was the more necessary, because, while the bird is on the tree, it repeats these motions almost incessantly, boring holes in the bark, and picking up the minutest insects, with the utmost celerity and precision. On meeting with an ant-hill, the woodpecker easily lays it open by the combined efforts of its feet and bill, and soon makes a plentiful meal of the ants and their eggs.

Among the Mammalia which have no teeth, the *Myrmecophaga*, or Ant-eater, practises a remarkable manœuvre for catching its prey. The tongue of this animal is very long and slender, and has a great resemblance to an earthworm: that of the two-toed ant-eater is very nearly one-third of the length of the whole body; and at its base is

* S is the large salivary gland on the right side.

† An account of this mechanism is given by Mr. Waller, in the Phil. Trans. for 1716, p. 509.

scarcely thicker than a crow-quill. It is furnished with a long and powerful muscle, which arises from the sternum, and is continued into its substance, affording the means of a quick retraction, as well as lateral motion; while its elongation and other movements are effected by circular fibres, which are exterior to the former. When laid on the ground in the usual track of ants, it is soon covered with these insects, and being suddenly retracted, transfers them into the mouth; and as, from their minuteness, they require no mastication, they are swallowed undivided, and without there being any necessity for teeth.

The lips of quadrupeds are often elongated for the more ready prehension of food, as we see exemplified in the *Rhinoceros*, whose upper lip is so extensible as to be capable of performing the office of a small proboscis. The *Sorex moschatus*, or musk shrew, whose favourite food is leeches, has likewise a very moveable snout, by which it gropes for, and seizes its prey from the bottom of the mud. More frequently, however, this office of prehension is performed by the tongue, which for that purpose is very flexible and much elongated, as we see in the *Camelopard*, where it acts like a hand in grasping and bringing down the branches of a tree.*

In the animals belonging to the genus *Felis*, the papillæ in the fore part of the tongue are each armed with a horny sheath terminating in a sharp point, which is directed backwards, so as to detain the food and prevent its escape. These prickles are of great size and strength in the larger beasts of prey, as the Lion and the Tiger; they are met with also in the Opossum, and in many species of bats, more especially those belonging to the genus *Pteropus:* all these horny productions have been regarded as analogous to the lingual teeth of fishes, already noticed.

The mouth of the *Ornithorhynchus* has a form of construction intermediate between that of quadrupeds and

* Home, Lectures, &c. vi. Plate 32.

birds; being furnished, like the former, with grinding teeth at the posterior part of both the upper and lower jaws, but they are of a horny substance; and the mouth is terminated in front by a horny bill, greatly resembling that of the duck, or the spoon-bill.

The *Whale* is furnished with a singular apparatus designed for filtration on a large scale. The palate has the form of a concave dome, and from its sides there descends perpendicularly into the mouth, a multitude of thin plates set parallel to each other, with one of their edges directed towards the circumference, and the other towards the middle of the palate. These plates are known by the name of *whalebone*, and their general form and appearance, as they hang from the roof of the palate, are shown in Fig. 272, which represents only six of these plates.* They are connected with the bone by means of a white ligamentous substance, to which they are immediately attached, and from which they appear to grow: at their inner margins, the fibres, of which their texture is throughout composed, cease to adhere together; but being loose and detached, form a kind of fringe, calculated to intercept, as in a sieve, all solid or even gelatinous substances that may have been admitted into the cavity of the mouth, which is exceedingly capacious; for as the plates of whalebone grow only from the margins of the upper jaw, they leave a large space within, which, though narrow anteriorly, is wider as it extends backwards, and is capable of holding a large quantity of

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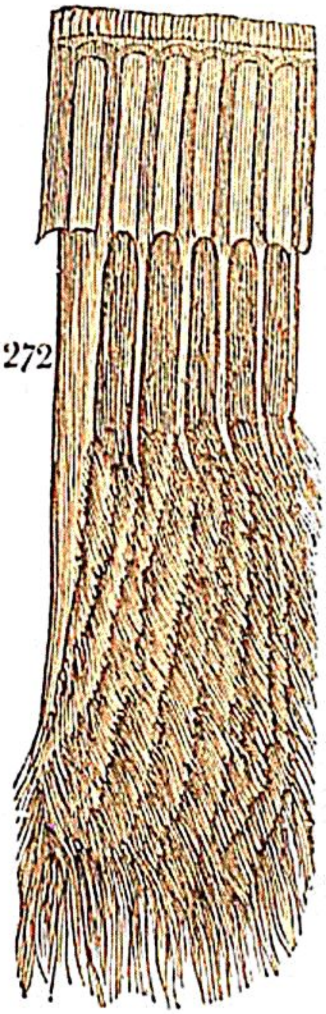


* In the *Piked Whale* the plates of whalebone are placed very near together, not being a quarter of an inch asunder; and there are above three hundred plates in the outer rows on each side of the mouth.

water. Thus, the whale is enabled to collect a whole shoal of mollusca, and other small prey, by taking into its mouth the sea water which contains these animals, and allowing it to drain off through the sides, after passing through the interstices of the net work formed by the filaments of the whalebone. Some contrivance of this kind was necessary to this animal, because the entrance into its œsophagus is too narrow to admit of the passage of any prey of considerable size; and it is not furnished with teeth to reduce the food into smaller parts. The principle food of the *Balæna Mysticetus*, or great whalebone whale of the Arctic Seas, is the small *Clio Borealis*, which swarms in immense numbers in those regions of the ocean; and which has been already delineated in Fig. 120.*

These remarkable organs for filtration entirely supersede the use of ordinary teeth; and, accordingly, no traces of teeth are to be discovered either in the upper or lower jaw. Yet a tendency to conform to the type of the mammalia is manifested in the early conformation of the whale; for rudiments of teeth exist in the interior of the lower jaw before birth, lodged in deep sockets, and forming a row on each side. The development of these imperfect teeth proceeds no farther; they even disappear at a very early period, and the groove which contained them closes over, and, after a short time, can no longer be seen. For the discovery of this curious fact we are indebted to Geoffroy St. Hilaire.† In connexion with this subject, an analogous fact, which has been noticed in the parrot, may here be mentioned. The young of the parrot, while still in the egg, presents a row of tubercles along the edge of the jaw, in external appearance exactly resembling the rudiments of teeth, but without being implanted into regular sockets in the maxillary bones: they are formed, however, by a process precisely similar to that of dentition; that is, by deposition from a vascular pulp, connected with the jaw. These tubercles are afterwards

* Vol. i. p. 186.

† Cuvier, Ossemens Fossiles, 3me edition, tom. v. p. 360.

consolidated into one piece in each jaw, forming, by their union the beak of the parrot, in a manner perfectly analogous to that which leads to the construction of the compound tooth of the elephant, and which I shall presently describe. The original indentations are obliterated as the beak advances in growth; but they are permanent in the bill of the duck, where the structure is very similar to that above described in the embryo of the parrot.

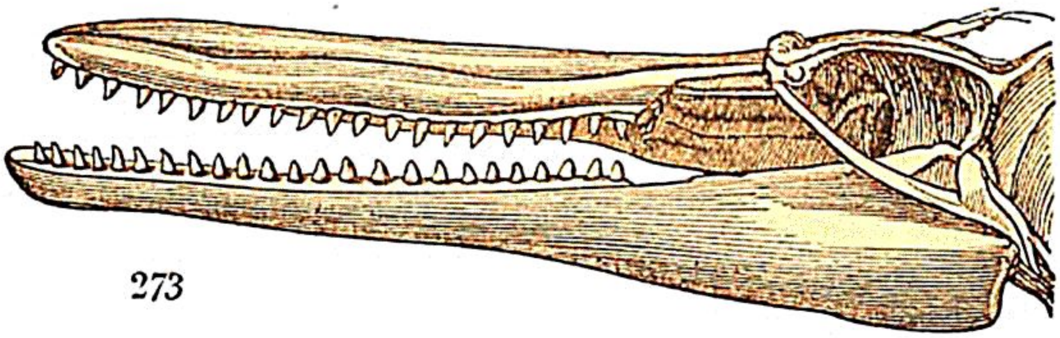
§ 3. *Mastication by means of Teeth.*

THE teeth, being essential instruments for seizing and holding the food, and effecting that degree of mechanical division necessary to prepare it for the chemical action of the stomach, perform, of course, a very important part in the economy of most animals; and in none more so than in the Mammalia, the food of which generally requires considerable preparation previously to its digestion. There exist, accordingly, the most intimate relations between the kind of food upon which each animal of this class is intended by nature to subsist, and the form, structure, and position of the teeth; and similar relations may also be traced in the shape of the jaw, in the mode of its articulation with the head, in the proportional size and distribution of the muscles which move the jaw, in the form of the head itself, in the length of the neck, and its position on the trunk, and, indeed, in the whole conformation of the skeleton. But since the nature of the appropriate food is at once indicated by the structure and arrangement of the teeth, it is evident that these latter organs, in particular, will afford to the naturalist most important characters for establishing a systematic classification of animals, and more especially of quadrupeds, where the differences among the teeth are very considerable; and these differences have, accordingly, been the object of much careful study. To the physiologist they present views of still higher interest, by exhibiting most striking evidences of the provident care with which every part of the organization of animals has been constructed, in exact reference to their respective wants and destinations.

The purposes answered by the teeth are principally those of seizing and detaining whatever is introduced into the mouth, of cutting it asunder, and dividing it into smaller pieces, of loosening its fibrous structure, and of breaking down and grinding its harder portions. Occasionally, some particular teeth are much enlarged, in order to serve as weapons of attack or of defence; for which purpose, they extend beyond the mouth, and are then generally denominated *tusks;* this we see exemplified in the *Elephant,* the *Narwhal,* the *Walrus,* the *Hippopotamus,* the *Boar,* and the *Babiroussa.*

Four principal forms have been given to teeth, which accordingly may be distinguished into the conical, the sharp-edged, the flat, and the tuberculated teeth; though we occasionally find a few intermediate modifications of these forms. It is easy to infer the particular functions of each class of teeth, from the obvious mechanical actions to which, by their form, they are especially adapted. The conical teeth, which are generally also sharp-pointed, are principally employed in seizing, piercing, and holding objects: such are the offices which they perform in the *Crocodile,* and other Saurian reptiles, where all the teeth are of this structure; and such are also their uses in most of the Cetacea, where similar forms and arrangements of teeth prevail. All the Dolphin tribe, such as the *Porpus,* the *Grampus,* and the *Dolphin,* are furnished with a uniform row of conical teeth, set round both jaws, in number amounting frequently to two hundred. Fig. 273, which represents the jaws of the Porpus, shows the form of these simply prehensile teeth.

The *Cachalot* has a similar row of teeth, which are, however, confined to the lower jaw. All these animals subsist upon fish, and their teeth are therefore constructed very much on the model of those of fish; while those Cetacea, on the other hand, which are herbivorous, as the *Manatus* and the *Dugong*, or Indian Walrus, have teeth very differently formed. The tusks of animals must necessarily, as respects their shape, be classed among the conical teeth.



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The sharp-edged teeth perform the office of cutting and dividing the yielding textures presented to them; they act individually as wedges or chisels, but when co-operating with similar teeth in the opposite jaw, they have the power of cutting like shears or scissors. The flat teeth, of which the surfaces are generally rough, are used in conjunction with those meeting them in the opposite jaw, for grinding down the food by a lateral motion, in a manner analogous to the operation of mill-stones in a mill. The tuberculated teeth, of which the surfaces present a number of rounded eminences, corresponding to depressions in the teeth opposed to them in the other jaw, act more by their direct pressure in breaking down hard substances, and pounding them, as in a mortar.

The position of the teeth in the jaws is another ground of distinction. In those Mammalia which exhibit the most complete set of teeth, the foremost in the row have the sharp-edged or chisel shape, constituting the blades of a cutting instrument; and they are accordingly denominated *incisors*. The incisors of the upper jaw are always implanted in a bone, intermediate between the two upper jaw bones, and called the *intermaxillary* bones.* The conical

* Those teeth of the lower jaw which correspond with the incisors of the upper jaw, are also considered as incisors. In Man, and in the species of quadrumana that most nearly resemble him, the sutures which divide the intermaxillary from the maxillary bones are obliterated before birth, and leave in the adult no trace of their former existence.

teeth, immediately following the incisors, are called *cuspidate*, or *canine* teeth, from their being particularly conspicuous in dogs; as they are, indeed, in all the purely carnivorous tribes. In the larger beasts of prey, as the lion and the tiger, they become most powerful weapons of destruction; in the boar they are likewise of great size, and constitute the tusks of the animal. All the teeth that are placed farther back in the jaw are designated by the general name of *molar teeth*, or *grinders*, but it is a class which includes several different forms of teeth. Those teeth which are situated next to the canine teeth, partake of the conical form, having pointed eminences; these are called the *false molar teeth*, and, also, from their having generally two points, or cusps, the *bicuspidate teeth*. The posterior molar teeth are differently shaped in carnivorous animals, for they are raised into sharp and often serrated ridges, having many of the properties of cutting teeth. In insectivorous and frugivorous animals their surface presents prominent tubercles, either pointed or rounded, for pounding the food; while in quadrupeds that feed on grass or grain, they are flat and rough, for the purpose simply of grinding.

The apparatus for giving motion to the jaws is likewise varied according to the particular movements required to act upon the food in the different tribes. The articulation of the lower jaw with the temporal bone of the skull, approaches to a hinge joint; but considerable latitude is allowed to its motions by the interposition of a moveable cartilage between the two surfaces of articulation, a contrivance admirably answering the intended purpose. Hence, in addition to the principal movements of opening and shutting, which are made in a vertical direction, the lower jaw has also some degree of mobility in a horizontal or lateral direction, and is likewise capable of being moved backwards and forwards, to a certain extent. The muscles which effect the closing of the jaw are principally the temporal and the masseter muscles; the former occupying the hollow of the temples, the latter connecting the lower angle of the jaw with the zygomatic arch. The lateral motions of the jaw are effected by muscles placed internally between the sides of the jaw and the basis of the skull.

In the conformation of the teeth and jaws, a remarkable contrast is presented between carnivorous and herbivorous animals. In the former, of which the *Tiger*, Fig. 274, may

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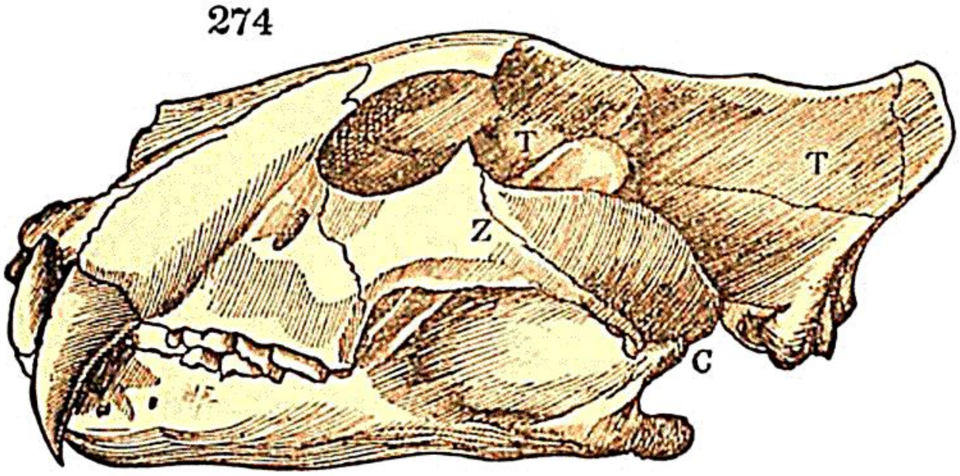

be taken as an example, the whole apparatus for mastication is calculated for the destruction of life, and for tearing and dividing the fleshy fibres. The molar teeth are armed with pointed eminences, which correspond in the opposite jaws so as exactly to lock into one another, like wheel-work, when the mouth is closed. All the muscles which close the jaw are of enormous size and strength, and they imprint the bones of the skull with deep hollows, in which we trace marks of the most powerful action. The temporal muscles occupy the whole of the sides of the skull (T, T;) and by the continuance of their vigorous exertions, during the growth of the animal, alter so considerably the form of the bones, that the skulls of the young and the old animals are often with difficulty recognised as belonging to the same species.* The process of the lower jaw (seen between T and T,) to which this temporal muscle is attached, is large and prominent; and the arch bone (Z,) from which the masseter arises, takes a wide span outwards, so as to give great strength to

* This is remarkably the case with the *Bear*, the skull of which exhibits, in old animals, a large vertical crest, not met with at an early period of life.

the muscle. The condyle, or articulating surface of the jaw (c,) is received into a deep cavity, constituting a strictly hinge joint, and admitting simply the motions of opening and shutting.

In herbivorous animals, on the contrary, as may be seen in the skull of the *Antelope*, Fig. 275, the greatest force is

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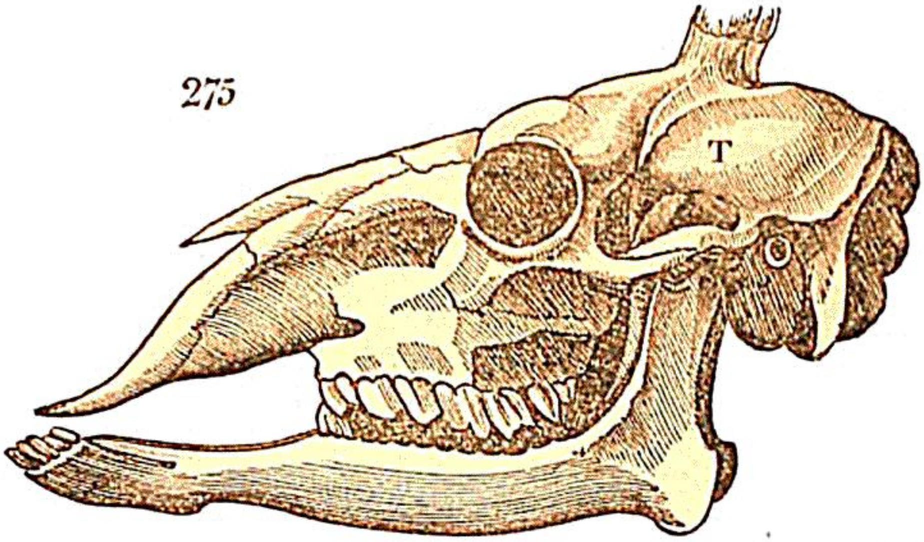

bestowed, not so much on the motions of opening and shutting, as on those which are necessary for grinding, and which act in a lateral direction. The temporal muscles, (occupying the space T,) are comparatively small and feeble; the condyles of the jaw are broad and rounded, and more loosely connected with the skull by ligaments; the muscles in the interior of the jaw, which move it from side to side, are very strong and thick; and the bone itself is extended downwards, so as to afford them a broad basis of attachment. The surfaces of the molar teeth are flattened and of great extent, and they are at the same time, by a provision which will be hereafter explained, kept rough, like those of millstones; their office being in fact very similar to that performed by these implements for grinding. All these circumstances of difference are exemplified in the most marked manner, in comparing together the skulls of the larger beasts of prey, as the tiger, the wolf, or the bear, with those of the antelope, the horse, or the ox.

The *Rodentia*, or gnawing quadrupeds, which I have already had occasion to notice, compose a well-marked family of Mammalia. These animals are formed for subsisting on dry and tough materials, from which but little nutriment can be extracted; such as the bark, and roots, and even the woody fibres of trees, and the harder animal textures, which would appear to be most difficult of digestion. They are all animals of diminutive size, whose teeth are expressly

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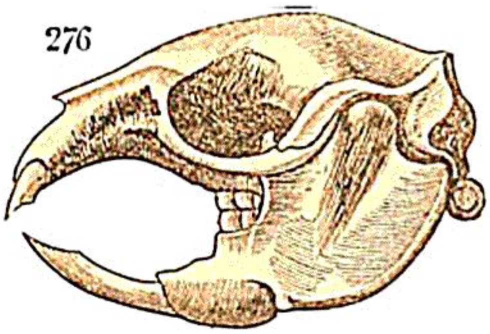

formed for gnawing, nibbling, and wearing away by continued attrition, the harder textures of organized bodies. The *Rat*, whose skull is delineated in Fig. 276, belongs, to this tribe. They are all furnished with two incisor teeth in each jaw, generally very long, and having the exact shape of a chisel; and the molar teeth have surfaces irregularly marked with raised zig-zag lines, rendering them very perfect instruments of trituration. The zygomatic arch is exceedingly slender and feeble; and the condyle is lengthened longitudinally to allow of the jaw being freely moved forwards and backwards, which is the motion for which the muscles are particularly adapted, and by which the grinding operation is performed. The *Beaver*, the *Rat*, the *Marmot*, and the *Porcupine*, present examples of this structure, among the omnivorous rodentia: and the *Hare*, the *Rabbit*, the *Squirrel*, among those which are principally herbivorous.

The *Quadrumana*, or Monkey tribes, approach nearest to the human structure in the conformation of their teeth, which appear formed for a mixed kind of food, but are especially adapted to the consumption of the more esculent fruits. The other orders of mammalia exhibit intermediate gradations in the structure of their teeth to those above described, corresponding to greater varieties in the nature of their food. Thus, the teeth and jaws of the *Hyena* are formed more especially for breaking down bones, and in so doing exert prodigious force; and those of the *Sea Otter* have rounded eminences, which peculiarly fit them for breaking shells.

The teeth, though composed of the same chemical ingredients as the ordinary bones, differ from them by having a greater density and compactness of texture, whence they derive that extraordinary degree of hardness which they require for the performance of their peculiar office. The substances of which they are composed are of three different kinds: the first, which is the basis of the rest, constituting the solid nucleus of the tooth, has been considered as the part most analogous in its nature to bone, but from its much greater density, and from its differing from bone in the mode of its formation, the name of *ivory* has been generally given to it. Its earthy ingredient consists almost entirely of phosphate of lime, the proportion of the carbonate of that earth entering into its composition being very small; and the animal portion is albumen, with a small quantity of gelatin.

A layer of a still harder substance, termed the *enamel*, usually covers the ivory, and, in teeth of the simplest structure, forms the whole of their outer surface: this is the

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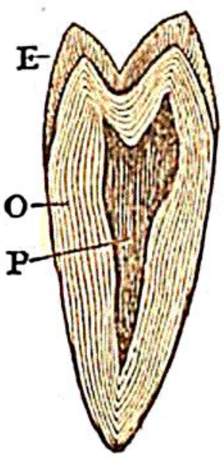

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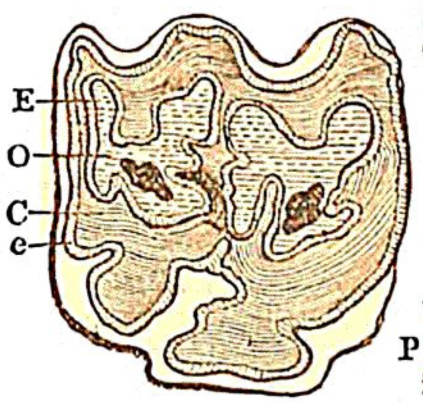

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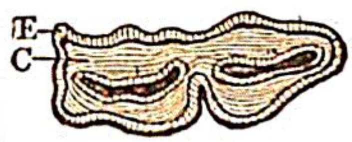

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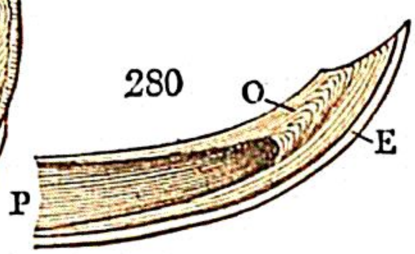


case with the teeth of man and of carnivorous quadrupeds. These two substances, and the direction of their layers, are seen in Fig. 277, which is the section of a simple tooth. E is the outer case of enamel, O the osseous portion, and P the cavity where the vascular pulp which formed it was lodged. The enamel is composed almost wholly of phosphate of lime, containing no albumen, and scarcely a trace of gelatin;

it is the hardest of all animal substances, and is capable of striking fire with steel. It exhibits a fibrous structure, approaching to a crystalline arrangement, and the direction of its fibres, as shown by the form of its fragments when broken, is every where perpendicular to the surface of the ivory to which it is applied. The ends of the fibres are thus alone exposed to the friction of the substances on which the teeth are made to act; and the effect of that friction in wearing the enamel is thus rendered the least possible.

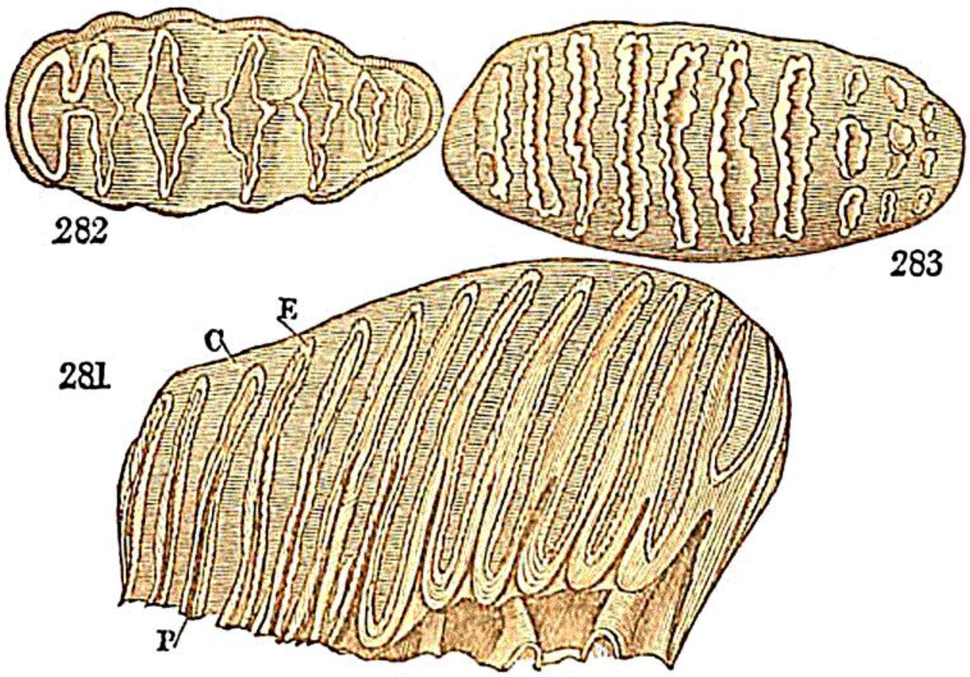
In the teeth of some quadrupeds, as of the *Rhinoceros* the *Hippopotamus*, and most of the Rodentia, the enamel is intermixed with the ivory, and the two so disposed as to form jointly the surface for mastication. In the progress ot life, the layers of enamel, being the hardest, are less worn down by friction than those of the ivory, and therefore form prominent ridges on the grinding surface, preserving it always in that rough condition, which best adapts it for the bruising and comminuting of hard substances.

The incisors of the rodentia are guarded by a plate of enamel on their anterior convex surfaces only; so that by the wearing down of the ivory behind this plate, a wedge-like form, of which the enamel constitutes the fine cutting edge, is soon given to the tooth, and is constantly retained as long as the tooth lasts (Fig. 280.) This mode of growth is admirably calculated to preserve these chisel teeth fit for use during the whole lifetime of the animal, an object of greater consequence in this descriptien of teeth than in others, which continue to grow only during a limited period. The same arrangement, attended with similar advantages, is adopted in the structure of the tusks of the *Hippopotamus*.

In teeth of a more complex structure, a third substance is found, uniting the vertical plates of ivory and enamel, and performing the office of an external cement. This substance has received various names, but it is most commonly known by that of the *Crusta petrosa:* it resembles ivory both in its composition and its extreme hardness; but is generally more opaque and yellow than that substance.

Other herbivorous quadrupeds, as the horse, and animals belonging to the ruminant tribe, have also complex teeth composed of these three substances; and their grinding surfaces present ridges of enamel intermixed in a more irregular manner with the ivory and crusta petrosa; but still giving the advantage of a very rough surface for trituration. Fig. 278 represents the grinding surface of the tooth of a horse, worn down by long mastication. E is the enamel, marked by transverse lines, showing the direction of its fibres, and enclosing the osseous portion (o,) which is shaded by interrupted lines. An outer coating of enamel (*e*) is also visible, and between that and the inner coat, the substance called *crusta petrosa* (c,) marked by waving lines, is seen. On the outside of all there is a plate of bone, which has been left white. In ruminants, the plates of enamel form crescents, which are convex outwardly in the lower, and inwardly in the upper jaw; thus providing for the crossing of the ridges of the two surfaces, an arrangement similar to that which is practised in constructing those of mill-stones. The teeth of the lower jaw fall within those of the upper jaw, so that a lateral motion is required in order to bring their surfaces opposite to each other alternately on both sides. Fig. 279 shows the grinding surface of the tooth of a *Sheep*, where the layers of bone are not apparent, there being only two layers of enamel (E,) and one of crusta petrosa (c.)

These three component parts are seen to most advantage in a vertical and longitudinal section of the grinding tooth of the elephant, in which they are more completely and equally intermixed than in that of any other animal. Fig. 281 presents a vertical section of the grinding tooth of the Asiatic Elephant, in the early stage of its growth, and highly polished, so as to exhibit more perfectly its three component structures. The enamel, marked E, is formed of transverse fibres; the osseous, or innermost structure is composed of longitudinal plates. The general covering of crusta petrosa, C, is less regularly deposited. P is the cavity which had been occupied by the pulp. In this tooth, which is still in a growing state, the fangs are not yet added, but they are, at one part, beginning to be formed. The same tooth, in its



usual state, as worn by mastication, gives us a natural and horizontal section of its interior structure, in which the plates of white enamel are seen forming waved ridges. These constitute, in the Asiatic Elephant, a series of narrow transverse bands, (Fig. 283,) and in the African Elephant, a series of lozenge-shaped lines, (Fig. 282,) having the ivory on their interior, and the yellow crusta petrosa on their outer sides; which latter substance also composes the whole circumference of the section.

§ 4. *Formation and development of the Teeth.*

Few processes in animal development are more remarkable than those which are employed to form the teeth; for they are, by no means, the same as those by which ordinary bone is constructed; and being commenced at a very early period, they afford a signal instance of Nature's provident anticipation of the future necessities of the animal. The teeth, being the hardest parts of the body, require a peculiar system of operations for giving them this extraordinary density, which no gradual consolidation could have imparted. The formation of the teeth is, in some respects, analogous to that of shell; inasmuch as all their parts, when once deposited, remain as permanent structures, hardly ever admitting of removal or of renewal by the vital powers. Unlike the bones, which contain within their solid substance vessels of different kinds, by which they are nourished, modified, and occasionally removed, the closeness of the texture of the teeth is such as to exclude all vessels whatsoever. This circumstance renders it necessary that they should originally be formed of the exact size and shape which they are ever after to possess: accordingly, the foundation of the teeth, in the young animal, are laid at a very early period of its evolution, and considerable progress has been made in their growth even prior to birth, and long before they can come into use.

A tooth of the simplest construction is formed from blood-vessels, which ramify through small masses of a gelatinous appearance; and each of these pulpy masses is itself enclosed in a delicate transparent vesicle, within which it grows till it has acquired the exact size and shape of the future tooth. Each vascular pulp is farther protected by an investing membrane of greater strength, termed its *capsule*, which is lodged in a small cavity between the two bony plates of the jaw. The vessels of the pulp begin at an early period to deposite the calcareous substance, which is to compose the ivory, at the most prominent points of that part of the vesicle, which corresponds in situation to the outer layer of the crown of the tooth. The thin scales of ivory thus formed increase by farther depositions made on their surfaces next to the pulp, till the whole has formed the first, or outer layer of ivory: in the mean time, the inner surface of the capsule, which is in immediate contact with this layer, secretes the substance that is to compose the enamel, and deposites it in layers on the surface of the ivory. This double operation proceeds step by step, fresh layers of ivory being deposited and building up the body of the tooth, and in the same proportion encroaching upon the cavity occupied by the pulp, which retires before it, until it is shrunk into a small compass, and fills only the small cavity which remains in the centre of the tooth. The ivory has by this time received from the capsule a complete coating of enamel, which constitutes the whole outer surface of the crown; after which no more is deposited, and the function of the capsule having ceased, it shrivels and disappears. But the formation of ivory still continuing at the part most remote from the crown, the fangs are gradually formed by a similar process from the pulp; and a pressure being thereby directed against the bone of the socket at the part where it is the thinnest, that portion of the jaw is absorbed, and the progress of the tooth is only resisted by the gum; and the gum, in its turn, soon yielding to the increasing pressure, the tooth cuts its way to the surface. This process of successive deposition is beautifully illustrated by feeding a young animal at different times with madder; the teeth which are formed at that period exhibiting, in consequence, alternate layers of red and of white ivory.*

The formation of the teeth of herbivorous quadrupeds, which have three kinds of substance, is conducted in a still more artificial and complicated manner. Thus, in the elephant, the pulp which deposites the ivory is extended in the form of a number of parallel plates; while the capsule which invests it, accompanies it in all its parts, sending down duplicatures of membrane in the intervals between the plates. Hence the ivory constructed by the pulp, and the enamel deposited over it, are variously intermixed; but besides this, the crusta petrosa is deposited on the outside of the enamel. Cuvier asserts that this deposition is made by the same capsule which has formed the enamel, and which, previously to this change of function, has become more spongy and vascular than before. But his brother, M. Frederic Cuvier,

* Cuvier. Dictionnaire des Sciences Médicales, t. viii. p. 320.

represents the deposite of crusta petrosa, as performed by a third membrane, wholly distinct from the two others, and exterior to them all, although it follows them in all their folds. In the horse and the ox, the projecting processes of the pulp, have more of a conical form, with undulating sides; and hence the waved appearance presented by the enamel, on making sections of the teeth of these animals.

The tusks of the elephant are composed of ivory, and are formed precisely in the same manner as the simple conical teeth already described, excepting that there is no outer capsule, and therefore no outer crust of enamel. The whole of the substance of the tusk is constructed by successive deposites of layers, having a conical shape, from the pulp which occupies the axis of the growing tusk; just as happens in the formation of a univalve shell which is not turbinated, as, for instance, the patella. Hence, any foreign substance, a bullet, for example, which may happen to get within the cavity occupied by the pulp, becomes, in process of time, encrusted with ivory, and remains embedded in the solid substance of the tusk. The pulp, as the growth of the tusk advances, retires in proportion as its place is occupied by the fresh deposites of ivory.

The young animal requires teeth long before it has attained its full stature; and these teeth must be formed of dimensions adapted to that of the jaw, while it is yet of small size. But, as the jaw enlarges, and the teeth it contains admit not of any corresponding increase, it becomes necessary that they should be shed to make room for others of larger dimensions, formed in a more capacious mould. Provision is made for this necessary change at a very early period of the growth of the embryo. The rudiments of the human teeth begin to form four or five months before birth: they are contained in the same sockets with the temporary teeth, the capsules of both being connected together. As the jaw enlarges, the second set of teeth gradually acquire their full dimensions, and then, by their outward pressure, occasion the absorption of the fangs of the temporary teeth, and, pushing them out, occupy their places.*

As the jaw bone, during its growth, extends principally backwards, the posterior portion, being later in forming, is comparatively of a larger size than either the fore or the lateral parts; and it admits, therefore, of teeth of the full size, which, consequently, are permanent. The molar teeth, which are last formed, are, for want of space, rather smaller than the others, and are called the *wisdom-teeth*, because they do not usually make their appearance above the gum till the person has attained the age of twenty. In the negro, however, where the jaw is of greater length, these teeth have sufficient room to come into their places, and are, in general, fully as large as the other molars.

The teeth of carnivorous animals are, from the nature of their food, less liable to be worn, than those of animals living on grain, or on the harder kinds of vegetable substances; so that the simple plating of enamel is sufficient to preserve them, even during a long life. But in many herbivorous quadrupeds we find that, in proportion as the front teeth are worn away in mastication, other teeth are formed, and advance from the back of the jaw to replace them. This happens, in a most remarkable manner, in the Elephant, and is the cause of the curved form which the roots assume; for, in proportion as the front teeth are worn away, those immediately behind them are pushed forwards by the growth of a new tooth at the back of the jaw; and this process goes on continually, giving rise to a succession of teeth, each of which is larger than that which has preceded it, during the whole period that the animal lives. A similar succession of teeth takes place in the *wild boar*, and, also, though to a less extent, in the *Sus Æthiopicus*.† This mode of dentition

* It is stated by Rousseau that the shedding of the first molar tooth both of the *Guinea-pig*, and the *Capibara*, and its replacement by the permanent tooth, take place a few days before birth. Anatomie Comparée du systême dentaire, p. 164.

† Home, Phil. Trans. for 1799, p. 237; and 1801, p. 319.

appears to be peculiar to animals of great longevity, and which subsist on vegetable substances containing a large proportion of tough fibres, or other materials of great hardness; and requiring for their mastication teeth so large as not to admit of both the old and new tooth being contained, at the same time, in the alveolar portion of the jaw.

An expedient of a different kind has been resorted to in the *Rodentia*, for the purpose of preserving the long chisel-shaped incisors in a state fit for use. By the constant and severe attrition to which they are exposed, they wear away very rapidly, and would soon be entirely lost, and the animal would perish in consequence, were it not that nature has provided for their continued growth, by elongation from their roots, during the whole of life. This growth proceeds in the same manner, and is conducted on the same principles, as the original formation of the simple teeth already described: but, in order to effect this object, the roots of these teeth are of great size and length, and are deeply embedded in the jaw, in a large bony socket provided for that purpose; and their cavity is always filled with the vascular pulp, from which a continued secretion and deposition of fresh layers, both of ivory and enamel, take place. The tusks of the *Elephant* and of the *Hippopotamus* exhibit the same phenomenon of constant and uninterrupted growth.

In the *Shark*, and some other fishes, the same object is attained in a different manner. Several rows of teeth are lodged in each jaw, but only one of these rows projects and is in use at the same time; the rest lying flat, but ready to rise in order to replace those which have been broken or worn down. In some fishes, the teeth advance in proportion as the jaw lengthens, and as the fore teeth are worn away: in other cases, they rise from the substance of the jaw, which presents on its surface an assemblage of teeth in different stages of growth: so that, in this class of animals, the greatest variety occurs in the mode of the succession of the teeth.

The teeth of the *Crocodile*, which are sharp-pointed hollow cones, composed of ivory and enamel, are renewed by the new tooth (as is shown at A, in Fig. 284,) being formed

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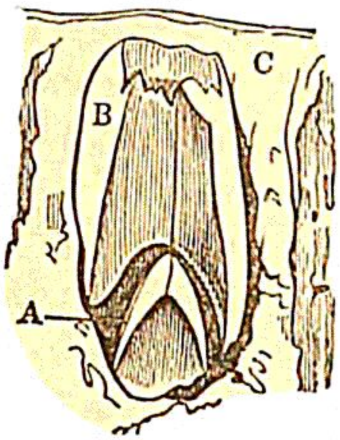


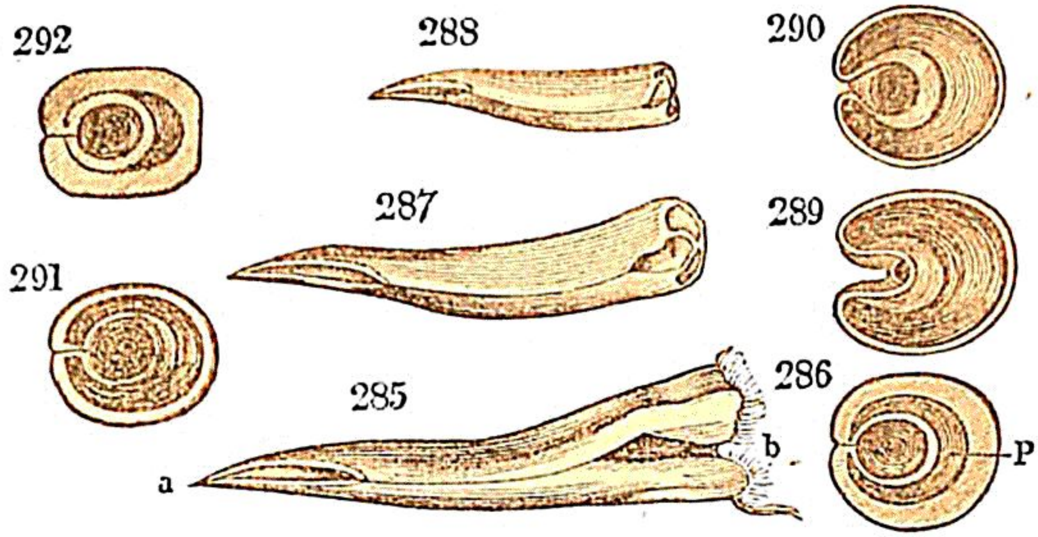
in the cavity of the one (B) which it is to replace, and not being enclosed in any separate cavity of the jaw bone (C.) As this new tooth increases in size, it presses against the base of the old one, and entering its cavity, acquires the same conical form; so that when the latter is shed, it is already in its place, and fit for immediate use. This succession of teeth takes place several times during the life of the animal, so that they are sharp and perfect at all ages.

The fangs of serpents are furnished, like the stings of nettles, with a receptacle at their base for a poisonous liquor, which is squeezed out by the pressure of the tooth, at the moment it inflicts the wound, and conducted along a canal, opening near the extremity of the tooth. Each fang is lodged in a strong bony socket, and is, by the intervention of a connecting bone, pressed forwards whenever the jaw is opened sufficiently wide; and the fang is thus made to assume an erect position. As these sharp teeth are very liable to accidents, others are ready to supply their places when wanted: for which purpose there are commonly provided two or three half-grown fangs, which are connected only by soft parts with the jaw, and are successively moved forwards into the socket to replace those that were lost.*

The tube through which the poison flows is formed by the folding in of the edges of a deep longitudinal groove, extending along the greater part of the tooth; an interval being left between these edges, both at the base and extremity of the fang, by which means there remain apertures at both ends for the passage of the fluid poison. This structure was discovered by Mr. T. Smith in the *Coluber naia*,

* Home, Lectures, &c. I. 333.

or, *Cobra de Capello;** and is shown in Fig. 285, which represents the full grown tooth, where the slight furrow, indicating the junction of the two sides of the original groove, may be plainly seen; as also the two apertures (a and b) above mentioned. This mode of formation of the tube is farther illustrated by Fig. 286, which shows a transverse



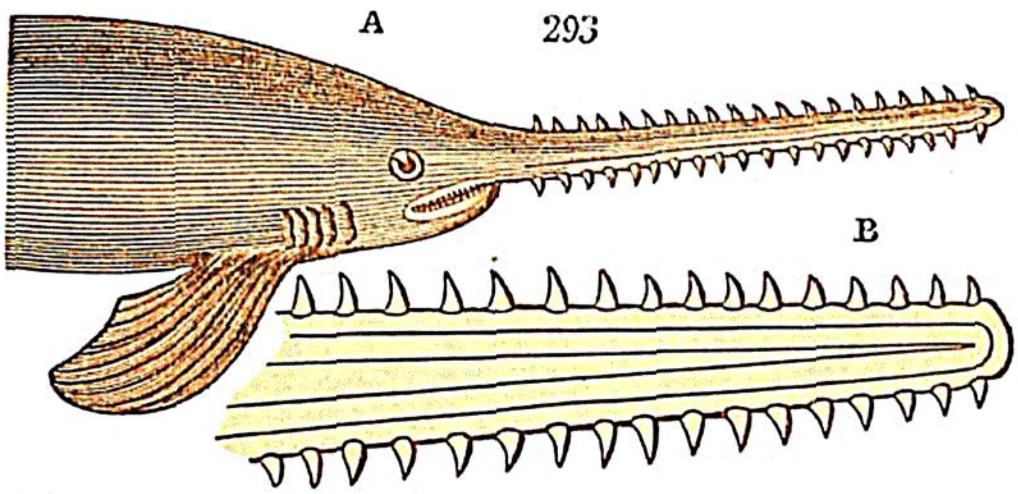
section of the same tooth, exhibiting the cavity (P) which contains the pulp of the tooth, and which surrounds that of the central tube in the form of a crescent. Figures 287 and 288 are delineations of the same tooth in different stages of growth, the bases of which, respectively, are shown in Figures 289 and 290. Figures 291 and 292 are magnified representations of sections of the fangs of another species of serpent, resembling the rattle-snake, Fig. 291 is a section of the young fang taken about the middle: in this stage of growth, the cavity which contains the pulp, almost entirely surrounds the poison tube, and the edges of the depression, which form the suture, are seen to be angular, and present so large a surface to each other, that the suture is completely filled up, even in this early stage of growth. Fig. 292 is a section of a full-grown fang of the same species of serpent, at the same part as the preceding; and here the cavity

* Philosophical Transactions, 1818, p. 471.

of the pulp is seen much contracted from the more advanced stage of growth.

It is a remarkable circumstance, noticed by Mr. Smith, that a similar longitudinal furrow is perceptible on every one of the teeth of the same serpent; and that this appearance is most marked on those which are nearest to the poisonous fangs: these furrows, however, in the teeth that are not venomous, are confined entirely to the surface, and do not influence the form of the internal cavity. No trace of these furrows is discernible in the teeth of those serpents which are not armed with venomous fangs.

Among the many instances in which teeth are converted to uses widely different from mastication, may be noticed that of the *Squalus pristis*, or Saw-fish, where the teeth are set horizontally on the two lateral edges of the upper jaw, which is prolonged in the form of a snout (seen in A, Fig. 293,) obviously constituting a most formidable weapon of



offence. B is a more enlarged view of a portion of this instrument, seen from the under side.

§. 5. *Trituration of Food in Internal Cavities.*

The mechanical apparatus, provided for triturating the harder kinds of food, does not belong exclusively to the mouth, or entrance into the alimentary canal, for in many animals we find this office performed by interior organs.

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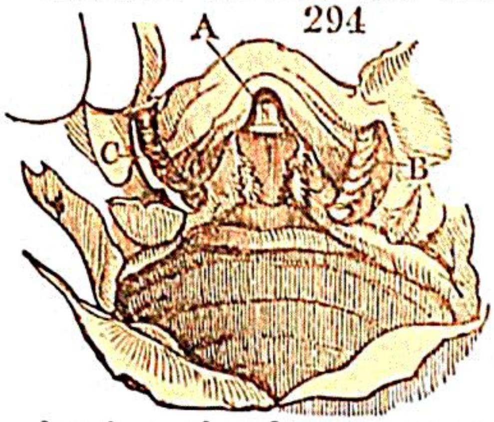

Among the inferior classes, we meet examples of this conformation in the Crustacea, the Mollusca, and above all in Insects. Thus, there is found in the stomach of the Lobster, a cartilaginous frame-work, in which are implanted hard calcareous bodies, having the form, and performing the functions of teeth. They are delineated in Fig. 294, which presents a view of the interior of the stomach of that animal. The tooth A is situated in the middle of this frame, has a rounded conical shape, and is smaller than the others (B, C,) which are placed one on each side, and which resemble in their form broad molar teeth. When these three teeth are brought together by the action of the surrounding muscles, they fit exactly into each other, and are capable of grinding and completely pulverizing the shells of the mollusca introduced into the stomach. These teeth are the result of a secretion of calcareous matter from the inner coat of that organ, just as the outer shell of the animal is a production of the integument: and at each casting of the shell, these teeth, together with the whole cuticular lining of the stomach to which they adhere, are thrown off, and afterwards renewed by a fresh growth of the same material. In the Craw-fish, the gastric teeth are of a different shape, and are more adapted to divide than to grind the food.

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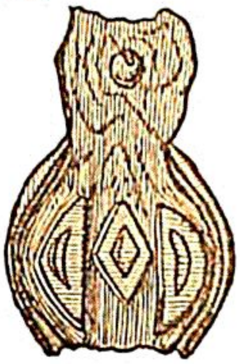

Among the gasteropodous Mollusca, several species of *Bullæ* have stomachs armed with calcareous plates, which act as cutting or grinding teeth. The *Bulla aperta* has three instruments of this description, as may be seen in Fig. 295, which shows the interior of the stomach of that species. Similar organs are found in the *Bulla lig-*

naria. The *Aplysia* has a considerable number of these gastric teeth. An apparatus of a still more complicated kind is provided in most of the insects belonging to the order of Orthoptera; but I shall not enter at present into a description of them, as it will be more convenient to include them in the general account of the alimentary canal of insects, which will be the subject of future consideration.

The internal machinery for grinding is exemplified on the largest scale in granivorous birds; where it forms part of the stomach itself, and is termed a *Gizzard.* It is shown in Fig. 298, representing the interior of the stomach of a *Swan.* Both the structure and the mode of operation of this organ bear a striking analogy to a mill for grinding corn, for it consists of two powerful muscles (G,) of a hemispherical shape, with their flat sides applied to each other, and their edges united by a strong tendon, which leaves a vacant space of an oval or quadrangular form between their two surfaces. These surfaces are covered by a thick and dense horny substance, which, when the gizzard is in action, performs an office similar to that of mill-stones. In most birds, there is likewise a sac, or receptacle, termed the *Craw,* (represented laid open at c) in which the food is collected for the purpose of its being dropped, in small quantities at a time, into the gizzard, in proportion as the latter gradually becomes emptied.* Thus, the analogy between this natural process and the artificial operation of a corn-mill is preserved even in the minuter details; for while the two flat surfaces of the gizzard act as mill-stones, the craw supplies the place, of the hopper, the office of which is

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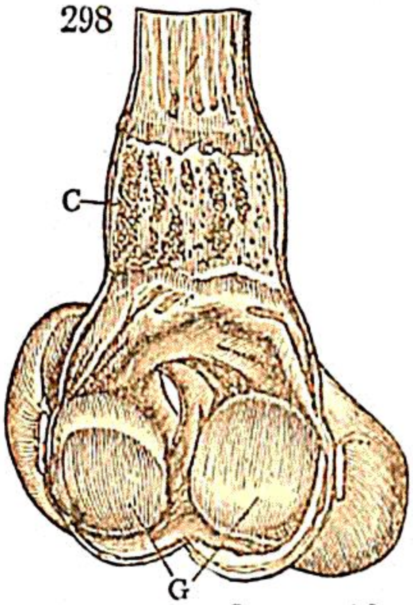

* The gastric glands, which are spread over the greater part of the internal surface of the craw, and which prepare a secretion for macerating the grain, are also seen in this part of the figure.

to allow the grain to pass out in small quantities into the aperture of the upper mill-stone, which brings it within the sphere of their action.

Innumerable are the experiments which have been made, particularly by Reaumur and Spallanzani, with a view to ascertain the force of compression exerted by the gizzard on its contents. Balls of glass, which the bird was made to swallow with its food, were soon ground to powder: tin tubes, introduced into the stomach, were flattened, and then bent into a variety of shapes; and it was even found that the points of needles and of lancets fixed in a ball of lead, were blunted and broken off by the power of the gizzard, while its internal coat did not appear to be in the slightest degree injured. These results were long the subject of admiration to physiologists; and being echoed from mouth to mouth, were received with a sort of passive astonishment, till John Hunter directed the powers of his mind to the inquiry, and gave the first rational explanation of the mechanism by which they are produced. He found that the motion of the sides of the gizzard, when actuated by its muscles, is lateral, and at the same time circular; so that the pressure it exerts, though extremely great, is directed nearly in the plane of the grinding surfaces, and never perpendicularly to them; and thus the edges and points of sharp instruments are either bent or broken off by the lateral pressure, without their having an opportunity of acting directly upon those surfaces. Still, however, it is evident that the effects produced upon sharp metallic points and edges, could not be accomplished by the gizzard without some assistance from other sources; and this assistance is procured in a very singular, and, at the same time, very effectual manner.

On opening the gizzard of a bird, it is constantly found to contain a certain quantity of small particles of gravel, which must have been swallowed by the animal. The most natural reason that can be assigned for the presence of these stones, is, that they aid the gizzard in triturating the contained food, and that they, in fact, supply the office of teeth in that operation. Spallanzani, however, has called in question the soundness of this explanation, and has contended that the pebbles found in the gizzard are swallowed merely by accident, or in consequence of the stupidity of the bird, which mistakes them for grain. But this opinion has been fully and satisfactorily refuted both by Fordyce and by Hunter, whose observations concur in establishing the truth of the common opinion, that in all birds possessing gizzards, the presence of these stones is essential to perfect digestion. A greater or less number of them is contained in every gizzard, when the bird has been able to meet with the requisite supply, and they are never swallowed but in order to assist digestion. Several hundred were found in the gizzard of a turkey; and two thousand in that of a goose: so great an accumulation could never have been the result of mere accident. If the alleged mistake could ever occur, we should expect it to take place to the greatest extent in those birds which are starving for want of food; but this is far from being the case. It is found that even chickens, which have been hatched by artificial heat, and which could never have been instructed by the parent, are yet guided by a natural instinct in the choice of the proper materials for food, and for assisting its digestion; and if a mixture of a large quantity of stones with a small proportion of grain be set before them, they will at once pick out the grain, and swallow along with it only the proper proportion of stones. The best proof of the utility of these substances may be derived from the experiments of Spallanzani himself, who ascertained that grain is not digested in the stomachs of birds, when it is protected from the effects of trituration.

Thus, the gizzard may, as Hunter remarks, be regarded as a pair of jaws, whose teeth are taken in occasionally to assist in this internal mastication. The lower part of the gizzard consists of a thin muscular bag, of which the office is to digest the food that has been thus triturated.

Considerable differences are met with in the structure of the gizzards of various kinds of birds, corresponding to differences in the texture of their natural food. In the *Turkey*, the two muscles which compose the gizzard are of unequal strength, that on the left side being considerably larger than that on the right; so that while the principal effort is made by the former, a smaller force is used by the latter to restore the parts to their situation. These muscles produce, by their alternate action, two effects; the one a constant trituration, by a rotatory motion; the other a continued, but oblique, pressure of the contents of the cavity. As this cavity is of an oval form, and the muscle swells inwards, the opposite sides never come into contact, and the interposed materials are triturated by their being intermixed with hard bodies. In the *Goose* and *Swan*, on the contrary, the cavity is flattened, and its lateral edges are very thin. The surfaces applied to each other are mutually adapted in their curvatures, a concave surface being every where applied to one which is convex: on the left side, the concavity is above; but on the right side, it is below. The horny covering is much stronger, and more rough, than in the turkey, so that the food is ground by a sliding, instead of a rotatory motion, of the parts opposed, and they do not require the aid of any intervening hard substances of a large size. This motion bears a great resemblance to that of the grinding teeth of ruminating animals, in which the teeth of the under jaw slide upwards, within those of the upper, pressing the food between them, and fitting it, by this peculiar kind of trituration, for being digested.*

§ 6. *Deglutition.*

The great object of the apparatus which is to prepare the food for digestion, is to reduce it into a soft pulpy state, so as to facilitate the chemical action of the stomach upon it: for this purpose, solid food must not only be subjected to mechanical trituration, but it must also be mixed with a cer-

* Home, Phil. Trans. for 1810, p. 188.

tain proportion of fluid. Hence, all animals that masticate their food are provided with organs which secrete a fluid, called the *Saliva*, and which pour this fluid into the mouth as near as possible to the grinding surfaces of the teeth. These organs are glands, placed in such a situation as to be compressed by the action of the muscles which move the jaw, and to pour out the fluid they secrete in greatest quantity, just at the time when the food is undergoing mastication. Saliva contains a large quantity of water, together with some salts and a little animal matter. Its use is not only to soften the food, but also to lubricate the passage through which it is to be conveyed into the stomach; and the quantity secreted has always a relation to the nature of the food, the degree of mastication it requires, and the mode in which it is swallowed. In animals which subsist on vegetable materials, requiring more complete maceration than those which feed on flesh, the salivary glands are of large size: they are particularly large in the *Rodentia*, which feed on the hardest materials, requiring the most complete trituration; and in these animals we find that the largest quantity of saliva is poured out opposite to the incisor teeth, which are those principally employed in this kind of mastication. In *Birds* and *Reptiles*, which can hardly be said to masticate their food, the salivary glands are comparatively of small size; the exceptions to this rule occurring chiefly in those tribes which feed on vegetables, for in these the glands are more considerable.* In *Fishes* there is no structure of this kind provided, there being no mastication performed: and the same observation applies to the *Cetacea*. In the cephalopodous and gasteropodous *Mollusca*, we find a salivary apparatus of considerable size: *Insects* and the *Annelida*,† also, generally present us with organs which appear to perform a similar office.

* The large salivary gland in the woodpecker, is seen at s, Fig. 271, page 99.

† The bunch of filaments, seen at s, Fig. 260 (p. 78) are the salivary organs of the leech.

The passage of the food along the throat is facilitated by the mucous secretions, which are poured out from a multitude of glands interspersed over the whole surface of the membrane lining that passage. The *Camel*, which is formed for traversing dry and sandy deserts, where the atmosphere as well as the soil is parched, is specially provided with a glandular cavity placed behind the palate, and which furnishes a fluid for the express purpose of moistening and lubricating the throat.

In the structure of the *Œsophagus*, which is the name of the tube along which the food passes from the mouth to the stomach, we may trace a similar adaptation to the particular kind of food taken in by the animal. When it is swallowed entire, or but little changed, the œsophagus is a very wide canal, admitting of great dilatation. This is the case with many carnivorous birds, especially those that feed on fishes, where its great capacity enables it to hold, for a considerable time, the large fish which are swallowed entire, and which could not conveniently be admitted into the stomach. Blumenbach relates that a sea-gull, which he kept alive for many years, could swallow bones of three or four inches in length, so that only their lower ends reached the stomach, and were digested, while their upper ends projected into the œsophagus, and descended gradually, in proportion as the former were dissolved. Serpents, which swallow animals larger than themselves, have, of course, the œsophagus, as well as the throat, capable of great dilatation, and the food occupies a long time in passing through it, before it reaches the digesting cavity. The turtle has also a capacious œsophagus, the inner coat of which is beset with numerous firm and sharp processes, having their points directed towards the stomach: these are evidently intended to prevent the return of the food into the mouth. Grazing quadrupeds, which, while they eat, carry their heads close to the ground, have a long œsophagus, with thick muscular coats, capable of exerting considerable power in propelling the food in the direction of the stomach, which is contrary to that of gravity.

§ 7. *Receptacles for retaining Food.*

PROVISION is often made for the retention of the undigested food in reservoirs, situated in different parts of the mouth, or the œsophagus, instead of its being immediately introduced into the stomach. These reservoirs are generally employed for laying in stores of provisions for future consumption. Many quadrupeds have cheek pouches for this purpose: this is the case with several species of Monkeys and Baboons: and, also, with the *Mus cricetus,* or Hamster. The *Mus busarius.* or Canada rat, has enormous cheek pouches, which, when distended with food, even exceed the bulk of the head. Small cheek pouches exist in that singular animal, the *Ornithorhynchus.* The *Sciurus palmarum,* or palm squirrel, is also provided with a pouch for laying in a store of provisions. A remarkable dilatation, in the lower part of the mouth and throat, answering a similar purpose, takes place in the *Pelican;* a bird which displays great dexterity in tossing about the fish with which it has loaded this bag, till it has brought it into the proper position for being swallowed. The *Whale* has also a receptacle of enormous size, extending from the mouth to a considerable distance under the trunk of the body.

Analogous in design to these pouches are the dilatations of the œsophagus of birds, denominated *crops.* In most birds which feed on grain, the crop is a capacious globular sac, placed in front of the throat, and resting on the furcular bone. The crop of the *Parrot* is represented at c, Fig. 299; where also, s indicates the cardiac portion of the stomach, and G the gizzard, of that bird. The inner coat of the crop is furnished with numerous glands, supplying considerable quantities of fluid for macerating and softening the dry and hard texture of the grain, which, for that purpose, remains there for a considerable time. Many birds feed their young from the contents of the crop; and, at those seasons its glands are much enlarged, and very active in preparing their peculiar secretions: this is remarkably the case in the *Pigeon*, which,

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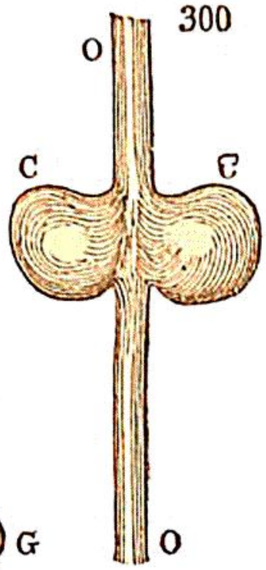

instead of a single sac, is provided with two, (seen at c, c, Fig. 300,) one on each side of the œsophagus (o.) The pouting pigeon has the faculty of filling these cavities with air, producing that distended appearance of the throat from which it derives its name. Birds of prey have, in general, very small crops, their food not requiring any previous softening; but the *Vulture*, which gorges large quantities of flesh at a single meal, has a crop of considerable size, forming, when filled, a visible projection in front of the chest. Birds which feed on fish have no separate dilatation for this purpose, probably because the great width of the œsophagus, and its having the power of retaining a large mass of food, render the farther dilatation of any particular part of the tube unnecessary. The lower portion of the œsophagus appears often, indeed, in this class of animals, to answer the purpose of a crop, and to effect changes in the food which may properly be considered as a preliminary stage of the digestive process.

CHAPTER VII.

Digestion.

All the substances received as food into the stomach, whatever be their nature, must necessarily undergo many changes of chemical composition before they can gain admission into the general mass of circulating fluids; but the extent of the change required for that purpose will, of course, be in proportion to the difference between the qualities of the nutritive materials in their original, and in their assimilated state. The conversion of vegetable into animal matter necessarily implies a considerable modification of properties; but even animal substances, however similar may be their composition to the body which they are to nourish, must still pass through certain processes of decomposition, and subsequent recombination, before they can be brought into the exact chemical state in which they are adapted to the purposes of the living system.

The preparatory changes we have lately been occupied in considering, consist chiefly in the reduction of the food to a soft consistence, which is accomplished by destroying the cohesion of its parts, and mixing them uniformly with the fluid secretions of the mouth; effects which may be considered as wholly of a mechanical nature. The first real changes in its chemical state are produced in the stomach, where it is converted into a substance termed *Chyme;* and the process by which this first step in the assimilation of the food is produced, constitutes what is properly termed *Digestion.*

Nothing has been discovered in the anatomical structure of the stomach, tending to throw any light on the means by which this remarkable chemical change is induced on the materials it contains. The stomach is, in most animals, a simple sac, composed of several membranes, enclosing thin layers of muscular fibres, abundantly supplied with blood-vessels and with nerves, and occasionally containing structures which appear to be glandular. The human stomach, which is delineated in Fig. 301, exhibits one of the simplest

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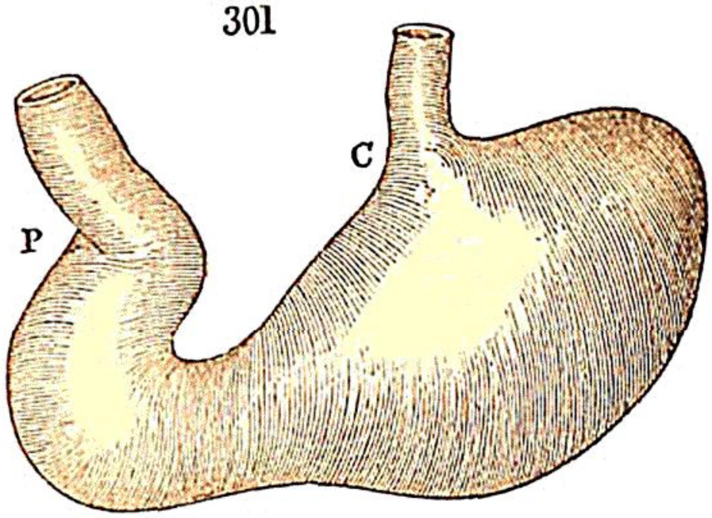

forms of this organ; c being the *cardiac portion*, or part where the œsophagus opens into it; and P the *pyloric portion*, or that which is near its termination in the intestine. At the pylorus itself, the diameter of the passage is much constricted, by a fold of the inner membrane, which is surrounded by a circular band of muscular fibres, performing the office of a sphincter, and completely closing the lower orifice of the stomach, during the digestion of its contents.

The principal agent in digestion, as far as the ordinary chemical means are concerned in that operation, is a fluid secreted by the coats of the stomach, and termed the *Gastric juice*. This fluid has, in each animal, the remarkable property of dissolving, or, at least, reducing to a pulp, all the substances which constitute the natural food of that particular species of animal; while it has comparatively but little solvent power over other kinds of food. Such is the conclusion which has been deduced from the extensive researches on this subject, made by that indefatigable experimentalist, Spallanzani, who found, in numberless trials, that the gastric juice taken from the stomach, and put into glass vessels, produced, if kept at the usual temperature of the animal, changes, to all appearance, exactly similar to those which take place in natural digestion.* In animals which feed on flesh, the gastric juice was found to dissolve only animal substances, and to exert no action on vegetable matter; while, on the contrary, that taken from herbivorous animals, acted on grass and other vegetable substances, without producing any effect on flesh; but in those animals, which, like man, are omnivorous, that is, partake indiscriminately of both species of aliment, it appeared to be fitted equally for the solution of both. So accurate an adaptation of the chemical powers of a solvent to the variety of substances employed as food by different animals, displays, in the most striking manner, the vast provision of nature, and the refined chemistry she has put in action for the accomplishment of her different purposes.

In the stomachs of many animals, as also in the human, it is impossible to distinguish with any accuracy the organization by which the secretion of the gastric juice is effected: but where the structure is more complex, there may be observed a number of glandular bodies interspersed in various parts of the internal coats of the stomach. These, which are termed the *Gastric glands*, are distributed in various ways in different instances: they are generally found in greatest number, and often in clusters, about the cardiac orifice of the stomach; and they are frequently intermixed with

* The accuracy of this conclusion has been lately contested by M. De Montégre, whose report of the effects of the gastric juice of animals out of the body, does not accord with that of Spallanzani; but the difference of circumstances in which his experiments were made, is quite sufficient to account for the discrepancy in the results; and those of M. De Montégre, therefore, by no means, invalidate the general facts stated in the text, which have been established by the experiments, not only of Spallanzani, but also of Reaumur, Stevens, Leuret, and Lassaigne. See Alison's Outlines of Physiology and Pathology, p. 170.

glands of another kind, which prepare a mucilaginous fluid, serving to protect the highly sensible coats of the stomach from injurious impressions. These latter are termed the *mucous glands*, and they are often constructed so as to pour their contents into intermediate cavities, or small sacs, which are denominated *follicles*, where the fluid is collected before it is discharged into the cavity of the stomach. The gastric glands of birds are larger and more conspicuous than those of quadrupeds; but, independently of those which are situated in the stomach, there is likewise found, in almost all birds, at the lower termination of the œsophagus, a large glandular organ, which has been termed the *bulbulus glandulosus*. In the *Ostrich*, this organ is of so great a size as to give it the appearance of a separate stomach. A view of the internal surface of the stomach of the African ostrich is given in Fig. 302; where C is the cardiac cavity, the coats

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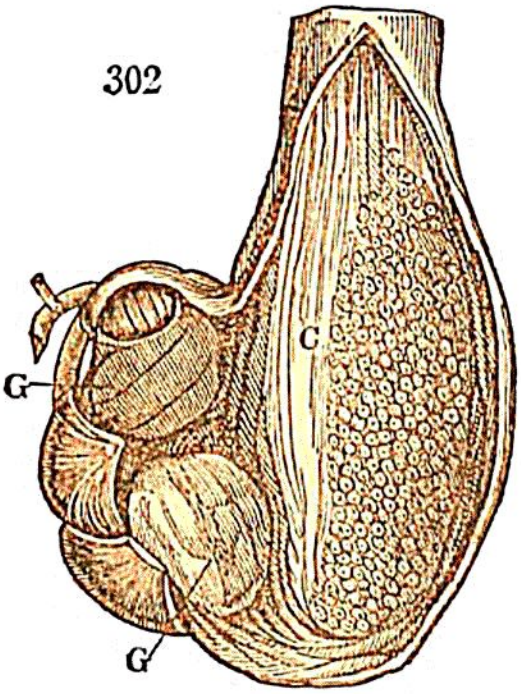

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of which are studded with numerous glands; G, G, are the two sides of the gizzard. Fig. 303 shows one of the gastric glands of the African ostrich; Fig. 304, a gland from the stomach of the American ostrich, and Fig. 305, a section of a gastric gland in the beaver, showing the branching of the ducts, which form three internal openings. In birds that live on vegetable food, the structure of the gastric glands is *evidently different from that of the corresponding* glands in predaceous birds; but as these anatomical details have not as yet tended to elucidate in any degree the purposes to which they are subservient in the process of digestion, I pass them over as being foreign to the object of our present inquiry.*

It is essential to the perfect performance of digestion, that every part of the food received into the stomach should be acted upon by the gastric juice; for which purpose provision is made that each portion shall, in its turn, be placed in contact with the inner surface of that organ. Hence the coats of the stomach are provided with muscular fibres, passing, some in a longitudinal, others in a transverse, or circular direction; while a third set have an oblique, or even spiral course.† When the greater number of these muscles act together, they exert a considerable pressure upon the contents of the stomach; a pressure which, no doubt, tends to assist the solvent action of the gastric juice. When different portions act in succession, they propel the food from one part to another, and thus promote the mixture of every *portion with the gastric juice. We often find that the mid*dle transverse bands contract more strongly than the rest, and continue contracted for a considerable time. The object of this contraction, which divides the stomach into two cavities, appears to be to separate its contents into two portions, so that each may be subjected to different processes; and, indeed, the differences in structure, which are often observable between these two portions of the stomach, would lead to the belief that their functions are in some respects different.

* These structures have been examined with great care and minuteness by Sir Everard Home, who has given the results of his inquiries in a series of papers, read from time to time to the Royal Society, and published in their Transactions.

† See Fig. 51, vol. i. p. 106, and its description, p. 107.

During digestion the exit of the food from the stomach into the intestine is prevented by the pylorus being closed by the action of its sphincter muscle. It is clear that the food is required to remain for some time in the stomach in order to be perfectly digested, and this closing of the pylorus appears to be one means employed for attaining this end; and another is derived from the property which the gastric juice possesses of coagulating, or rendering solid, every animal or vegetable fluid susceptible of undergoing that change. This is the case with fluid albumen; the white of an egg, for instance, which is nearly pure albumen, is very speedily coagulated when taken into the stomach; the same change occurs in milk, which is immediately curdled by the juices that are there secreted, and these effects take place quite independently of any acid that may be present. The object of this change from fluid to solid appears to be to detain the food for some time in the stomach, and thus to allow of its being thoroughly acted upon by the digestive powers of that organ. Those fluids which pass quickly through the stomach, and thereby escape its chemical action, however much they may be in themselves nutritious, are very imperfectly digested, and consequently afford very little nourishment. This is the case with oils, with jelly, and with all food that is much diluted.* Hunter ascertained

* A diet consisting of too large a proportion of liquids, although it may contain much nutritive matter, yet if it be incapable of being coagulated by the stomach, will not be sufficiently acted upon by that organ to be properly digested, and will not only afford comparatively little nourishment, but be very liable to produce disorder of the alimentary canal. Thus, soups will not prove so nutritive when taken alone, as when they are united with a certain proportion of solid food, capable of being detained in the stomach, during a time sufficiently long to allow of the whole undergoing the process of digestion. I was led to this conclusion, not only from theory, but from actual observation of what took place among the prisoners in the Milbank Penitentiary, in 1823, when, on the occasion of the extensive prevalence of scorbutic dysentery in that prison, Dr. P. M. Latham and myself were appointed to attend the sick, and inquire into the origin of the disease. Among the causes which concurred to produce this formidable malady, one of the most prominent appeared to be an impoverished diet, consisting of a

that this coagulating power belongs to the stomach of every animal which he examined for that purpose, from the most perfect down to reptiles;* and Sir E. Home has prosecuted the inquiry with the same result, and ascertained that this property is possessed by the secretion from the gastric glands, which communicates it to the adjacent membranes.†

The gastric juice has also the remarkable property of correcting putrefaction. This is particularly exemplified in animals that feed on carrion, to whom this property is of great importance, as it enables them to derive wholesome nourishment from materials which would otherwise taint the whole system with their poison, and soon prove destructive to life.

It would appear that the first changes which constitute digestion take place principally at the cardiac end of the stomach, and that the mass of food is gradually transferred towards the pylorus, the process of digestion still continuing as it advances. In the *Rabbit* it has been ascertained that food newly taken into the stomach is always kept distinct from that which was before contained in it, and which has begun to undergo a change: for this purpose the new food is introduced into the centre of the mass already in the stomach; so that it may come in due time to be applied to the coats of that organ, and be in its turn digested, after the same change has been completed in the latter.‡

As the flesh of animals has to undergo a less considerable change than vegetable materials, so we find the stomachs of all the purely carnivorous tribes consisting only of a membranous bag, which is the simplest form assumed by this or-

large proportion of soups, on which the prisoners had subsisted for the preceding eight months. A very full and perspicuous account of that disease has been drawn up, with great ability, by my friend Dr. P. M. Latham, and published under the title of "An account of the disease lately prevalent in the General Penitentiary." London, 1825.

* Observations on the Animal Economy, p. 172.

† Phil. Trans. for 1813, p. 96.

‡ See Dr. Philip's Experimental Inquiry into the Laws of the Vital Functions, 3d edition, p. 122.

gan. But in other cases, as we have already seen, the stomach exhibits a division into two compartments by means of a slight contraction; a condition which, as Sir E. Home has remarked, is sometimes found as a temporary state of the human stomach;* while, in other animals, it is its natural and permanent conformation. The *Rodentia* furnish many examples of this division of the cavity into two distinct portions, which exhibit even differences in their structure: this is seen in the *Dormouse*, (Fig. 306,) the *Beaver*, the *Hare*, the *Rabbit*, and the cape *Hyrax*, (Fig. 307.) The first or cardiac portion is often lined with cuticle, while the

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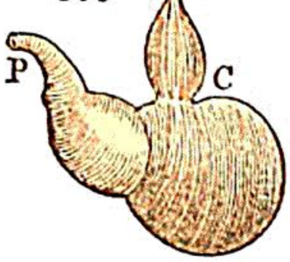

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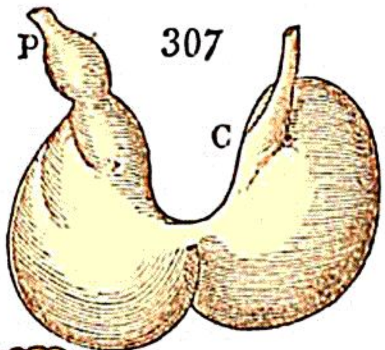

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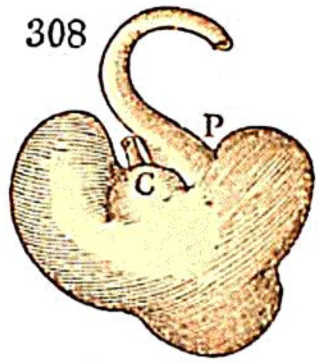

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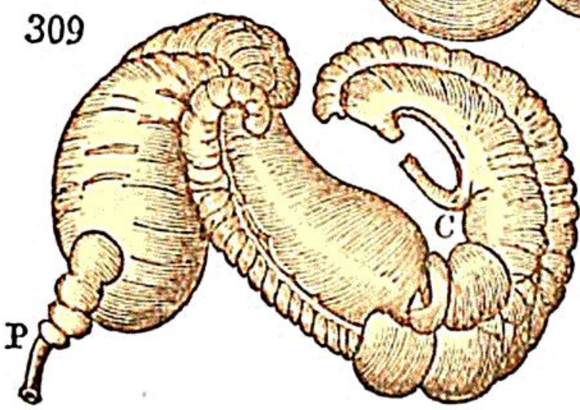

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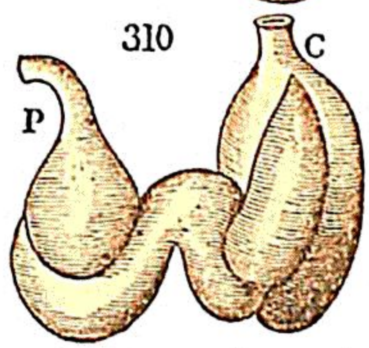

lower portion is not so lined; as is seen very conspicuously in the stomachs of the *Solipeda*. The stomach of the Horse, in particular, is furnished at the cardia with a spiral fold of the inner, or cuticular membrane, which forms a complete valve, offering no impediment to the entrance of food from the œsophagus, but obstructing the return of any part of the contents of the stomach into that passage.† This

* The figure given of the human stomach, p. 133, shows it in the state of partial contraction here described.

† The total inability of a horse to vomit is probably a consequence of the impediment presented by this valve. See Mem. du Muséum d'Hist. Nat. viii. 111.

valve is shown in Fig. 311, which represents an inner view of the cardiac portion of the stomach of the horse; o being the termination of the œsophagus.

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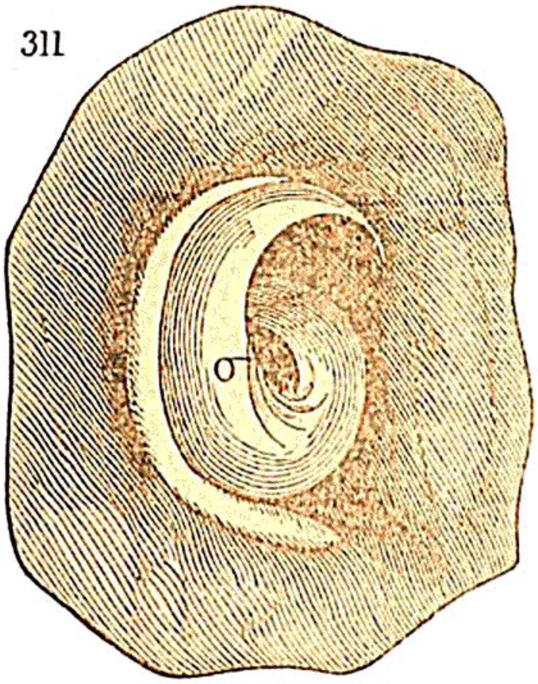

The stomach of the *Water Rat* is composed of two distinct cavities, having a narrow passage of communication: the first cavity is lined with cuticle, and is evidently intended for the maceration of the food before it is submitted to the agents which are to effect its digestion; a process which is completed in the second cavity, provided, for that purpose, with a glandular surface.

In proportion as nature allows of greater latitude in diet, we find her providing greater complication in the digestive apparatus, and subdividing the stomach into a greater number of cavities, each having probably a separate office assigned to it, though concurring in one general effect. A gradation in this respect may be traced through a long line of quadrupeds, such as the *Hog*, the *Peccari*, the *Porcupine*, (Fig. 308,) and the *Hippopotamus*, where we find the number of separate pouches for digestion amounting to four or five. Next to these we may rank the very irregular stomach of the *Kanguroo*, (Fig. 309) composed of a multitude of cells, in which the food probably goes through several preparatory processes; and still greater complication is exhibited by the stomachs of the *Cetacea*, as, for example, in that of the Porpus (Fig. 310.) As the fishes upon which this animal feeds are swallowed whole, and have large sharp bones, which would injure any surface not defended by cuticle, receptacles are provided, in which they may be softened and dissolved, and even converted into nourishment, by themselves, and without interfering with the digestion of the soft parts. The narrow communications between these several stomachs of the cetacea are probably intended to ensure the thorough solution of their contents, by preventing the exit of all such portions as have not perfectly undergone this process.

Supernumerary cavities of this kind, belonging to the stomach, are more especially provided in those animals which swallow food either in larger quantity than is immediately wanted, or of a nature which requires much preparation previous to digestion. The latter is more particularly the case with the horned ruminant tribes that feed on the leaves or stalks of vegetables, a kind of food, which, in proportion to its bulk, affords but little nutriment, and requires, therefore, a long chemical process, and a complicated digestive apparatus, in order to extract from it the scanty nutritious matter it contains, and prepare it for being applied to the uses of the system. This apparatus is usually considered as consisting of four stomachs; and, in order to convey a distinct idea of this kind of structure, I have selected for representation, in Fig. 312, that of the *Sheep*, of which the

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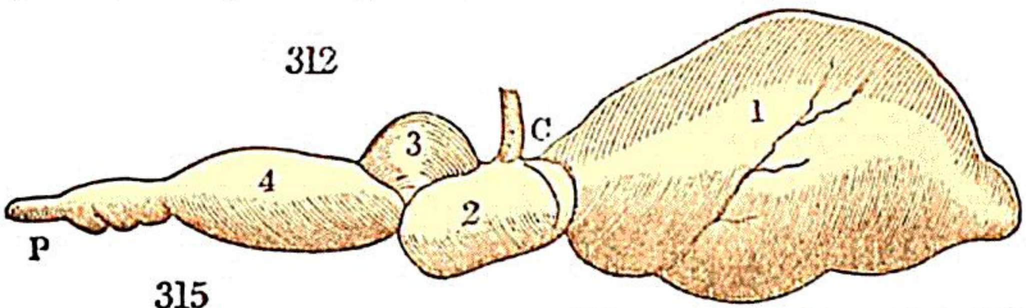

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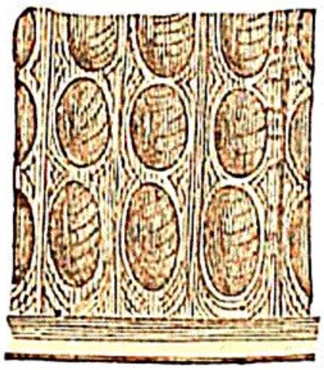

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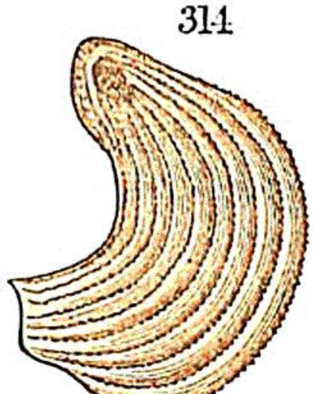

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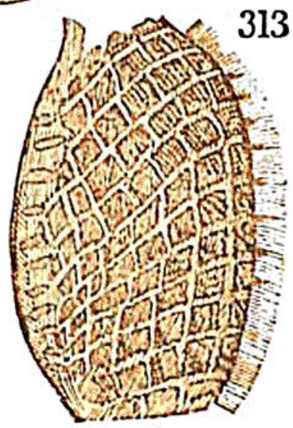

four stomachs are marked by the numbers 1, 2, 3, 4, respectively, in the order in which they occur, when traced from the œsophagus (c) to the intestine (P.)

The grass, which is devoured in large quantities by these animals, and which undergoes but little mastication in the mouth, is hastily swallowed, and is received into a capacious reservoir, marked 1 in the figure, called the *paunch*. This cavity is lined internally with a thick membrane, beset with numerous flattened papillæ, and is often divided into pouches by transverse contractions. While the food remains in this bag, it continues in rather a dry state; but the moisture with which it is surrounded contributes to soften it, and to prepare it for a second mastication; which is effected in the following manner. Connected with the paunch is another, but much smaller sac (2,) which is considered as the second stomach; and, from its internal membrane being thrown into numerous irregular folds, forming the sides of polygonal cells, it has been called the *honey-comb stomach*, or *reticule*. Fig. 313 exhibits the reticulated appearance of the inner surface of this cavity. A singular connexion exists between this stomach and the preceding; for, while the œsophagus appears to open naturally into the paunch, there is, on each side of its termination, a muscular ridge, which projects from the orifice of the latter, so that the two together form a channel leading into the second stomach; and thus the food can readily pass from the œsophagus into either of these cavities, according as the orifice of the one or the other is open to receive it.

It would appear from the observations of Sir E. Home, that liquids drank by the animal pass at once into the second stomach, the entrance into the first being closed. The food contained in the paunch is transferred, by small portions at a time, into this second, or honey-comb stomach, in which there is always a supply of water for moistening the portion of food introduced into it. It is in this latter stomach, then, that the food is rolled into a ball, and thrown up, through the œsophagus, into the mouth, where it is again masticated at leisure, and while the animal is reposing; a process which is well known by the name of *chewing the cud*, or *rumination*.

When the mass, after being thoroughly ground down by the teeth, is again swallowed, it passes along the œsophagus into the third stomach (3,) the orifice of which is brought forwards by the muscular bands, forming the two ridges already noticed, which are continued from the second stomach, and which, when they contract, effectually prevent any portion of the food from dropping into either of the preceding cavities. In the ox, this third stomach is described by Sir E. Home, as having the form of a crescent, and as containing twenty-four *septa*, or broad folds of its inner membrane. These folds are placed parallel to one another, like the leaves of a book, excepting that they are of unequal breadths, and that a narrower fold is placed between each of the broader ones. Fig. 314 represents this plicated structure in the interior of the third stomach of a bullock. Whatever food is introduced into this cavity, which is named, from its foliated structure, the *many-plies stomach*, must pass between these folds, and describe three-fourths of a circle, before it can arrive at the orifice leading to the fourth stomach, which is so near that of the third, that the distance between them does not exceed three inches. There is, however, a more direct channel of communication between the œsophagus and the fourth stomach (4,) along which milk taken by the calf, and which does not require to be either macerated or ruminated, is conveyed directly from the œsophagus to this fourth stomach; for, at that period, the folds of the many-plies stomach are not yet separated, and adhere closely together; and, in these animals, rumination does not take place, till they begin to eat solid food. It is in this fourth stomach, which is called the *reed*, that the proper digestion of the food is performed, and it is here that the coagulation of the milk takes place; on which account the coats of this stomach are employed in dairies, under the name of *rennet*, to obtain curd from milk.

A regular gradation in the structure of ruminating stomachs may be traced in the different genera of this family of quadrupeds. In ruminants with horns, as the bullock and the sheep, there are two preparatory stomachs for retaining the food previous to rumination, a third for receiving it after it has undergone this process, and a fourth for effecting its digestion. Ruminants without horns, as the Camel, Dromedary, and Lama, have only one preparatory stomach before rumination, answering the purpose of the two first stomachs of the bullock; a second, which I shall presently notice, and which takes no share in digestion, being employed merely as a reservoir of water; a third, exceedingly small, and of which the office has not been ascertained; and a fourth, which receives and digests the food after rumination. Those herbivorous animals which do not ruminate, as the horse and ass, have only one stomach; but the upper portion of it is lined with cuticle, and appears to perform some preparatory office, which renders the food more easily digestible by the lower portion of the same cavity.*

The remarkable provision above alluded to in the *Camel*, an animal which nature has evidently intended as the inhabitant of the sterile and arid regions of the East, is that of reservoirs of water, which, when once filled, retain their contents for a very long time, and may minister not only to the wants of the animal that possesses it, but, also, to those of man. The second stomach of the Camel has a separate compartment, to which is attached a series of cellular appendages; (exhibited, on a small scale, in Fig. 315;) in these the water is retained by strong muscular bands, which close the orifices of the cells, while the other portions of the stomach are performing their usual functions. By the relaxation of these muscles, the water is gradually allowed to mix with the contents of the stomach, and thus the Camel is enabled to support long marches across the desert, without receiving any fresh supply. The Arabs, who traverse those extensive plains, accompanied by these useful animals, are, it is said, sometimes obliged, when faint, and in danger of perishing from thirst, to kill one of their camels, for the sake

* Home, Phil. Trans. 8vo. 1806, p. 370.

of the water contained in these reservoirs, which they always find to be pure and wholesome. It is stated by those who have travelled in Egypt, that camels, when accustomed to go journeys, during which they are for a long time deprived of water, acquire the power of dilating the cells, so as to make them contain a more than ordinary quantity, as a supply for their journey.*

When the Elephant, while travelling in very hot weather, is tormented by insects, it has been observed to throw out from its proboscis, directly upon the part on which the flies fix themselves, a quantity of water, with such force as to dislodge them. The quantity of water thrown out is in proportion to the distance of the part attacked, and is commonly half a pint at a time: and this, Mr. Pierard, who resided many years in India, has known the elephant to repeat eight or ten times within the hour. This water is not only ejected immediately after drinking, but six or eight hours afterwards. The quantity of water at the animal's command for this purpose, observes Sir E. Home, cannot be less than six quarts; and on examining the structure of the stomach of that animal, he found in it a cavity, like that of the camel, perfectly well adapted to afford this occasional supply of water, which may probably, at other times, be employed in moistening dry food for the purposes of digestion.†

In every series of animals belonging to other classes, a correspondence may be traced, as has been done in the Mammalia, between the nature of the food and the conformation of the digestive organs. The stomachs of birds, reptiles, and fishes, are, with certain modifications, formed very much upon the models of those already described, according as the food consists of animal or of vegetable materials, or presents more or less resistance from the cohesion of its texture. As it would be impossible, in this place, to enter into all the de-

* Home, Lectures on Comparative Anatomy, vol. i. p. 171.

† Supplement to Sir E. Home's Lectures on Comparative Anatomy, vol. vi. p. 9.

tails necessary for fully illustrating this proposition, I must content myself with indicating a few of the most general results of the inquiry.*

As the food of birds varies, in different species, from the softest animal matter to the hardest grain, so we observe every gradation in their stomachs, from the membranous sac of the carnivorous tribes, which is one extreme, to the true gizzard of granivorous birds, which occupies the other extremity of the series. This gradation is established by the muscular fibres, which surround the former, acquiring, in different tribes, greater extent, and forming stronger muscles, adapted to the corresponding variations in the food, more especially in as far as it partakes of the animal or vegetable character.

In all the cold-blooded vertebrata, where digestion is not assisted by any internal heat, that operation proceeds more slowly, though in the end not less effectually, than in animals where the contents of the stomach are constantly maintained at a high temperature. They almost all rank as carnivorous animals, and have accordingly stomachs, which, however they may vary in their form, are alike simply membranous in their structure, and act by means of the solvent power of their secretions. Among *Reptiles*, only a few exceptions occur to this rule. The common Sea-turtle which is brought to our tables, is one of these; for it is found to feed exclusively on vegetable diet, and chiefly on the sea-weed called *zostira maritima;* but though very muscular, it has not the cuticular lining which forms an essential character of a gizzard. Some Tortoises, also, which eat grass, make an approach to the same structure.

In fishes, indeed, although the membranous structure of

* The comparative anatomy of the stomach has been investigated with great diligence by the late Sir E. Home, and the results recorded in the papers he communicated, from time to time, to the Royal Society, and which have been republished in his splendid work, entitled "Lectures on Comparative Anatomy," to which it will be seen that I have been largely indebted for the facts and observations relating to this subject, detailed in the text.

the stomach invariably accompanies the habit of preying upon other fish, yet there is one species of animal food, namely, shell-fish, which requires to be broken down by powerful means before it can be digested. In many fish, which consume food of this kind, its trituration is effected by the mouth, which is, for this purpose, as I have already noticed in the wolf-fish, armed with strong grinding teeth. But in others, an apparatus similar to that of birds is employed; the office of mastication being transferred to the stomach. Thus, the *Mullet* has a stomach endowed with a degree of muscular power, adapting it, like the gizzard of birds, to the double office of mastication and digestion; and the stomach of the *Gillaroo trout*, a fish peculiar to Ireland, exhibits nearly the same structure as that of the turtle. The common trout, also, occasionally lives upon shell-fish, and swallows stones to assist in breaking the shells.

Among the invertebrated classes we occasionally meet with instances of structures exceedingly analogous to a gizzard, and probably performing the same functions. Such is the organ found in the *Sepia;* the earth-worm has both a crop and a gizzard; and insects offer numerous instances, presently to be noticed, of great complexity in the structure of the stomach, which is often provided, not only with a mechanism analogous to a gizzard, but also with rows of gastric teeth.

CHAPTER VIII.

Chylification.

The formation of Chyle, or the fluid which is the immediate and exclusive source of nutriment to the system, takes place in the intestinal tube, into which the chyme prepared by the stomach is received, and where farther chemical changes are effected in its composition. The mode in which the conversion of chyme into chyle is accomplished, and indeed the exact nature of the changes themselves, being, as yet, very imperfectly known, it is consequently impossible to trace distinctly the correspondence which, in all cases, undoubtedly exists between the objects to be answered and the means employed for their attainment. No doubt can be entertained of the importance of the functions which are performed by structures so large and so complicated as those composing the alimentary canal, and its various appendages. We plainly perceive that provision is made in the interior of that canal, for subjecting its contents to the action, first, of an extensive vascular and nervous surface; and secondly, of various fluid secretions, derived from different sources, and exercising powerful chemical agencies on the digested aliment; that a muscular power is supplied, by means of the layers of circular and longitudinal fibres, contained between the outer and inner coats of the intestine,* for exerting a certain pressure on their contents, and for propelling them forwards by a succession of contractions, which constitutes what is termed their *peristaltic motion;* and lastly, that contrivances are at the same time resorted to for retarding the progress of the aliment in its passage

* See vol. i. p. 106.

along the canal, so that it may receive the full action of these several agents, and yield the utmost quantity of nutriment it is capable of affording.

The total length of the intestinal tube differs much in different animals, being in general, as already stated, smaller in the carnivorous tribes, than those which feed on substances of difficult digestion, or affording but little nourishment. In these latter animals, the intestine is always of great length, exceeding that of the body many times; hence it is obliged to be folded into a spiral or serpentine course, forming many convolutions in the abdominal cavity. Sometimes, probably for greater convenience of package, instead of these numerous convolutions, a similar effect of increasing the surface of the inner membrane is obtained by raising it into a great number of folds, which project into the cavity. These folds are often of considerable breadth, contributing not only to the extention of the surface for secretion and absorption, but also to the detention of the materials, with a view to their more complete elaboration. Remarkable examples of this kind of structure occur in most of the cartilaginous fishes, when the inner coat of the large intestine being expanded into a broad fold, which, as is seen in fig. 316, representing this structure in the interior of the intestine of the shark, takes a spiral course; and this is continued nearly the whole length of the canal, so that the internal surface is much augmented without any increase in the length of the intestine.*

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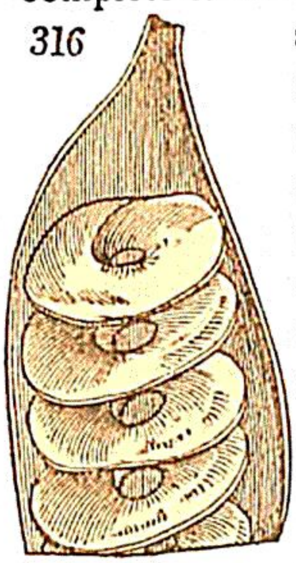


When the nature of the assimilatory process is such as to require the complete detention of the food, for a certain time, in particular situations, we find this object provided for by means of *cæca*, or separate pouches

* Structures of this description have a particular claim to attention, from the light they throw on the nature of several fossil remains, lately investigated with singular success by Dr. Buckland.

opening laterally from the cavity of the intestine, and having no other outlet. Structures of this description have already been noticed in the infusoria,* and they are met with, indeed, in animals of every class, occurring in various parts of the alimentary tube, sometimes even as high as the pyloric portion of the stomach, and frequently at the commencement of the small intestine. Their most usual situation, however, is lower down, and especially at the part where the tube, after having remained narrow in the first half of its course, is dilated into a wider cavity, which is distinguished from the former by the appellation of the great intestine, and which is frequently more capacious than the stomach itself. It is exceedingly probable that these two portions of the canal perform different functions in reference to the assimilation of the food: but hitherto no clew has been discovered to guide us through the intricacies of this difficult part of physiology; and we can discern little more than the existence already mentioned, of a constant relation between the nature of the aliment and the structure of the intestines, which are longer, more tortuous, and more complicated, and are furnished with more extensive folds of the inner membrane, and with larger and more numerous cæca, in animals that feed on vegetable substances, than in carnivorous animals of the same class.

The class of *Insects* supplies numberless exemplifications of the accurate adaptation of the structure of the organs of assimilation to the nature of the food which is to be converted into nutriment, and also of the general principle that vegetable aliment requires for this purpose longer processes and a more complicated apparatus, than that which has been already animalized. In the herbivorous tribes, we find the œsophagus either extremely dilatable, so as to serve as a crop, or receptacle for containing the food previous to its digestion, or having a distinct pouch appended to it for the same object: to this there generally succeeds a gizzard, or apparatus for

* Page 73, of this volume.

trituration, furnished, not merely with a hard cuticle, as in birds, but also with numerous rows of teeth, of various forms, answering most effectually the purpose of dividing, or grinding into the minutest fragments, all the harder parts of the food, and thus supplying any deficiency of power in the jaws for accomplishing the same object. Thence the aliment, properly prepared, passes into the cavity appropriated for its digestion, which constitutes the true stomach.* In the lower part of this organ a peculiar fluid secretion is often intermixed with it, which has been supposed to be analogous to the bile of the higher animals. It is prepared by the coats of slender tubes, termed hepatic vessels, which are often of great length, and sometimes branched or tufted, or beset, like the fibres of a feather, with lateral rows of filaments, and which float loosely in the general cavity of the body, attached only at their termination, where they open into the alimentary canal.† In some insects, these tubes are of larger diameter than in others; and in many of the orthoptera, as we shall presently see, they open into large receptacles, sometimes more capacious than the stomach itself, which have been supposed to serve the purpose of reservoirs of the biliary secretion, pouring it into the stomach on those occasions only when it is particularly wanted for the completion of the digestive process.‡

* It is often difficult to distinguish the portions of the canal, which correspond in their functions to the stomach, and to the first division of the intestines, or *duodenum;* so that different naturalists, according to the views they have taken of the peculiar office of these parts, have applied to the same cavity the term of *chyliferous stomach*, or of *duodenum*. See the memoir of Léon Dufour, in the Annales des Sciences Naturelles, ii. 473.

† The first trace of a secreting structure, corresponding to hepatic vessels, is met with in the *Asterias*, where the double row of minute lobes attached to the cæcal stomachs of those animals, and discharging their fluid into these cavities, are considered by Carus, as performing a similar office. The flocculent tissue which surrounds the intestine of the *Holothuria*, is probably, also, an hepatic apparatus.

‡ A doubt is suggested, by Léon Dufour, whether the liquid found in those pouches is real bile, or merely aliment in the progress of assimilation. Ann. Sc. Nat. ii. 478.

The distinction into small and great intestine is more or less marked, in different insects, in proportion to the quantities of food consumed, and to its vegetable nature; and in herbivorous tribes, more especially, the dilatations in the lower part of the canal are most conspicuous, as well as the duplicatures of the inner membrane, which constitute imperfect valves for retarding the progress of the aliment. It is generally at the point where this dilatation of the canal commences, that a second set of hepatic vessels is inserted, having a structure essentially the same as those of the first set, but generally more slender, and uniting into a small number of ducts before they terminate. The number and complication of both these sets of hepatic vessels, appear to have some relation to the existence and development of the gizzard, and consequently, also, to the nature and bulk of the food. Vessels of this description are, indeed, constantly found in insects; but it is only where a gizzard exists, that two sets of these secreting organs are provided; and in some larvæ, remarkable for their excessive voracity, even three orders of hepatic vessels are met with.*

A muscular power has also been provided, not only for the strong actions exerted by the gizzard, but, also, for the necessary propulsion, in different directions, of the contents both of the stomach and intestinal tubes. The muscular fibres of the latter are distinctly seen to consist of two sets, the one passing in a transverse or circular, and the other in a longitudinal direction. Glandular structures, analogous to the mucous follicles of the higher animals, are also plainly distinguishable in the internal coat of the canal, more especially of herbivorous insects.† The whole tract of the alimentary canal is attached to the sides of the containing cavity by a fine membrane, or *peritoneum* containing numerous air-vessels, or *tracheæ*.‡

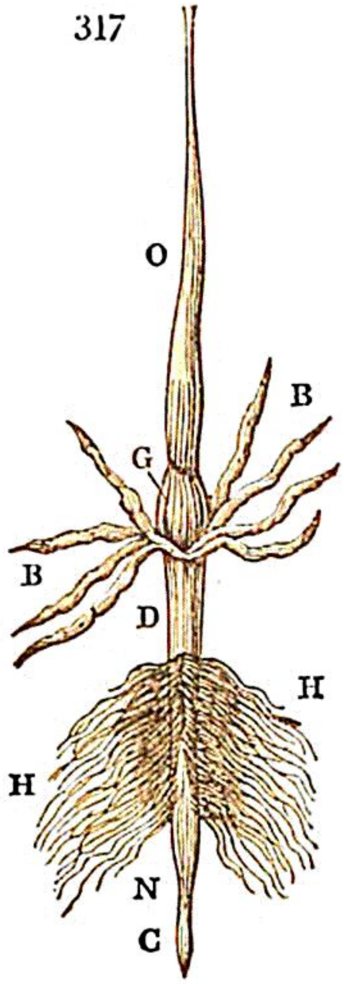
* See the memoirs of Marcel de Serres, in the Annales du Muséum, xx. 48.

† Lyonet.

‡ It has been stated by Malpighi and by Swammerdam, and the statement

To engage in a minute description of the endless variations in the structure of the digestive organs, presented in the innumerable tribes which compose this class of animals, would be incompatible with the limits of this treatise. I shall content myself, therefore, with giving a few illustrations of their principal varieties, selected from those in which the leading characters of structure are most strongly marked. I shall, with this view, exhibit first one of the simplest forms of the alimentary organs, as they occur in the *Mantis religiosa*, (Linn.) which is a purely carnivorous insect belonging to the order o Orthoptera. Fig. 317 represents those of this insect, freed from their attachments, and separated from the body. The whole canal, as is seen, is perfectly straight: it commences by an œsophagus (O,) of great length, which is succeeded by a gizzard (G;) at the lower extremity of this organ the upper hepatic vessels (B, B,) eight in number, and of considerable diameter, are inserted: then follows a portion of the canal (D,) which may be regarded either as a digesting stomach, or a chyliferous duodenum: farther downwards, the second set of hepatic vessels (H H,) which are very numerous, but as slender as hairs, are received; and after a small contraction (N) there is again a slight dilatation of the tube (C) before it terminates.

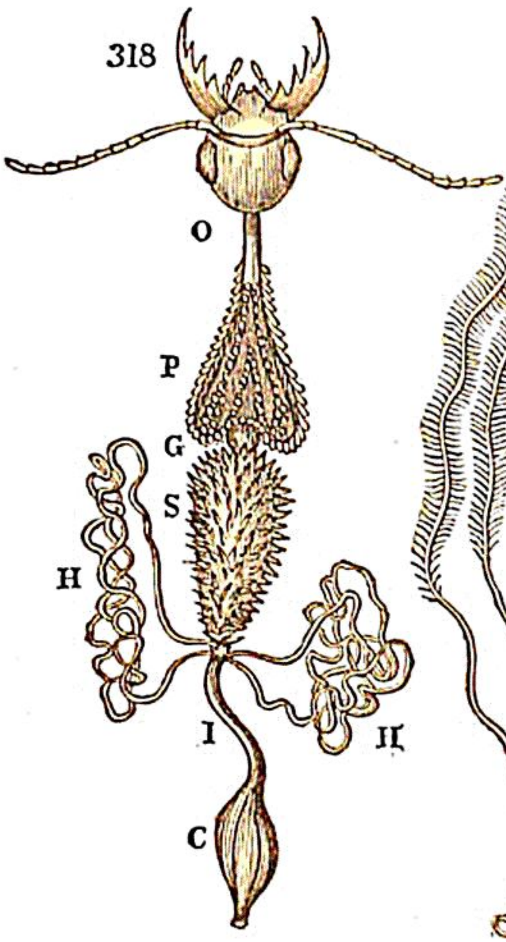
317



has been repeated by every succeeding anatomist; that almost all the insects belonging to the tribe of *Grylli*, possessed the faculty of ruminating their food; but this error has been refuted by Marcel de Serres, who has offered satisfactory evidence that in no insect is the food subjected to a true rumination, or second mastication, by the organs of the mouth. See Annales du Muséum, xx. 51 and 364.

The alimentary canal of the *Cicindela campestris*, (Lin.) which preys on other insects, is represented in Fig. 318; where we see that the lower part of the œsophagus (O,) is dilated into a crop (P,) succeeded by a small gizzard (G,) which is provided for the purpose of bruising the elytera, and other hard parts of their victims; but, this mechanical division being once effected, we again find the true digesting stomach (S) simply membranous, and the intestine (I) very short, but dilated, before its termination, into a large colon (C.) The hepatic vessels (H,) of which, in this insect, there is only one set, terminate in the cavity of the intestine by four ducts, at the point where that canal commences.

318



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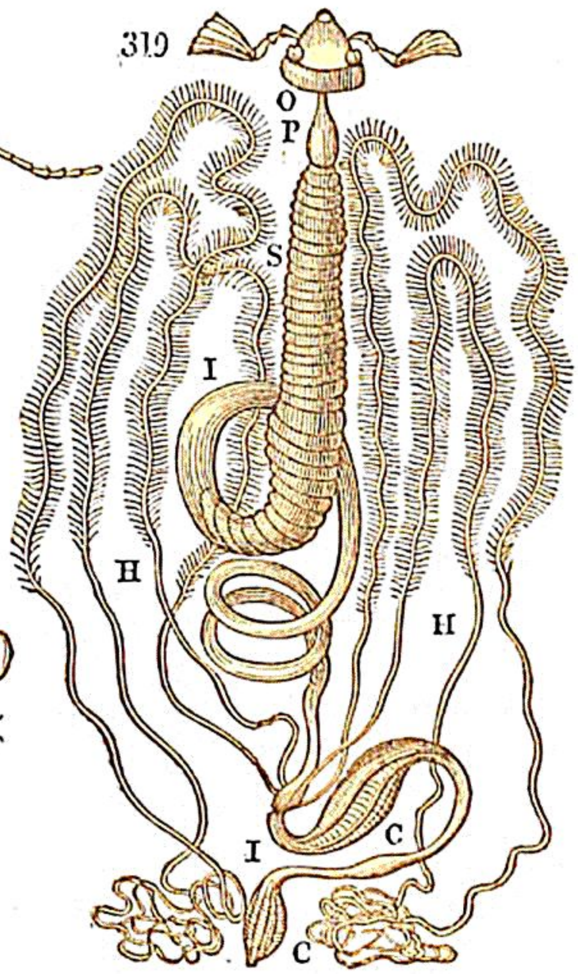

A more complicated structure is exhibited in the alimentary tube of the *Melolontha vulgaris*, or common cockchaffer, which is a vegetable feeder, devouring great quantities of leaves of plants, and consequently requiring a long and capacious canal for their assimilation; as is shown in Fig. 319, which represents them prepared in a manner similar to the former. In this herbivorous insect, the œsophagus (o) is, as might be expected, very short, and is soon dilated into a crop (P;) this is followed by a very long, wide, and muscular stomach (S,) ringed like an earth-worm, and continued into a long and tortuous intestine (I, I,) which presents in its course several dilatations (C, C,) and receives very elongated, convoluted, and ramified hepatic vessels (H, H.) Fig. 320 is a highly magnified view of a small portion of one of these vessels, showing its branched form.

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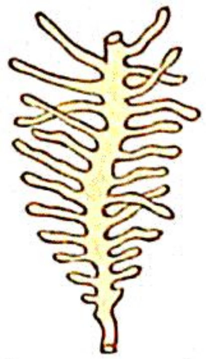
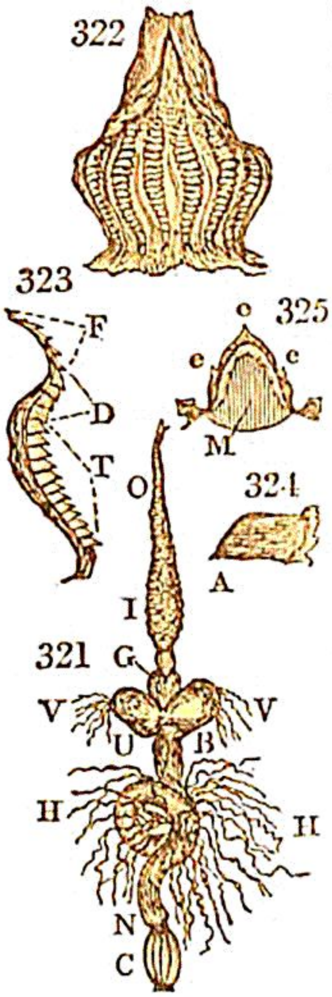


In the alimentary canal (Fig. 321*) of the *Acrida aptera* (Stephens,) which is a species of grasshopper, feeding chiefly on the dewberry, we observe a long œsophagus (O,) which is very dilatable, enlarging occasionally into a crop (I,) and succeeded by a rounded or heart-shaped gizzard (G,) of very complicated structure, and connected with two remarkably large biliary pouches (U and B,) which receive, at their anterior extremity, the upper set of hepatic vessels (V, V.) A deep furrow in the pouch (B,) which, in the horizontal position of the body, lies underneath the gizzard, divides it apparently into two sacs. The intestinal canal is pretty uniform in its diameter, receives in its course a great number of hepatic vessels (H H,) by separate openings, and after making one convolution, is slightly constricted at N: it is then dilated into a colon (C,) on the



* The figures relating to this insect were engraved from the drawings of Mr. Newport, who was also kind enough to supply me with the description of the parts they represent. Fig. 321 is twice the natural size.

coats of which the longitudinal muscular bands are very distinctly seen. Fig. 322 is a magnified view of the gizzard laid open, to show its internal structure. It is furnished with six longitudinal rows of large teeth, and six intermediate double rows of smaller teeth; the total number of teeth being 270. One of the rows of large teeth is seen, detached, and still more magnified, in Fig. 323; it contains at the upper part, five small hooked teeth (F,) succeeded below by four broad teeth (D,) consisting of quadrangular plates, and twelve tricuspid teeth (T;) that is, teeth having three cusps, or points at their edges. Fig. 324 shows the profile of one of these teeth; A, being the sharp point by which the anterior acute angle of the base terminates. Fig. 325 exhibits the base of the same tooth seen from below, c, c, c, being the three cusps, and M, the triangular hollow space for the insertion of the muscles which move them, and which compose part of the muscular apparatus of the gizzard. The smaller teeth, which are set in double lines between each of the larger rows, consist of twelve small triangular teeth in each row. All the teeth contained in this organ are of a brown colour and horny texture, resembling tortoise shell.

The same insect, as we have seen, often exhibits, at different periods of its existence, the greatest contrast, not only in external form, but also, in its habits, instincts, and modes of subsistence. The larva is generally remarkable for its voracity, requiring large supplies of food to furnish the materials for its rapid growth, and frequently consuming enormous quantities of fibrous vegetable aliment: the perfect insect, on the other hand, having attained its full dimensions, is sufficiently supported by small quantities of a more nutritious food, consisting either of animal juices, or of the fluids prepared by flowers, which are generally of a saccharine quality, and contain nourishment in a concentrated form. It is evident that the same apparatus, which is necessary for the digestion of the bulky food taken in during the former period, would not be suited to the assimilation of that which is received during the latter; and that in order to accommodate it to this altered condition of its function, considerable changes must be made in its structure. Hence, it will be interesting to trace the gradual transitions in the conformation of the alimentary canal, during the progressive development of the insect, and more especially while it is undergoing its different metamorphoses.

These changes are most conspicuous in the Lepidoptera, where we may observe the successive contractions which take place in the immensely voluminous stomach of the caterpillar, while passing into the state of chrysalis, and thence into that of the perfect insect, in which its form is so changed that it can hardly be recognised as the same organ. I have

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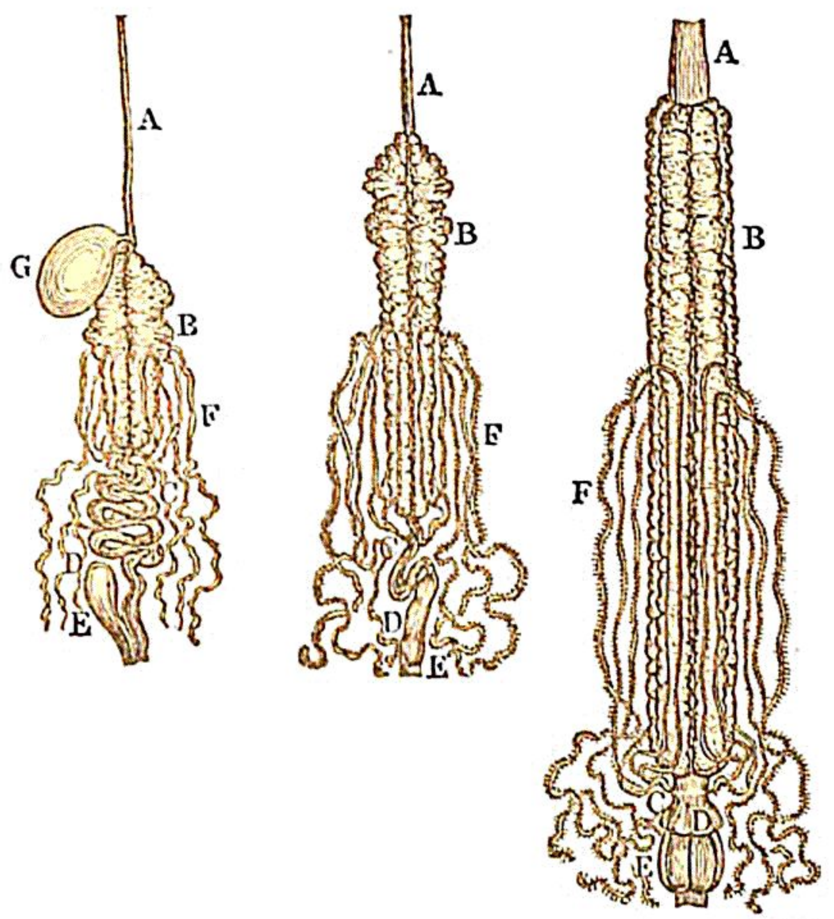

given representations of these three different states of the entire alimentary canal of the *Sphinx ligustri*, or Privet Hawk-moth, in Figures 326, 327, and 328;* the first of which

* These figures also have been engraved from the drawings of Mr. Newport, which he was so obliging as to make for me, from preparations of his own, the result of very careful dissections.

is that of the caterpillar; the second, that of the chrysalis; and the third, that of the moth. The whole canal and its appendages, have been separated from their attachments, and spread out so as to display all their parts; and they are delineated of the natural size, in each case, so as to show their comparative dimensions in these three states. In all the figures, A is the œsophagus; B, the stomach; C, the small intestine; D, the cæcal portion of the canal; and E, the colon, or large intestine. The hepatic vessels are shown at F; and the gizzard, which is developed only in the moth, at G, Fig. 328.

It will be seen that in the caterpillar, (Fig. 326,) the stomach forms, by far the most considerable portion of the alimentary tube, and that it bears some resemblance in its structure and capacity to the stomachs of the Annelida, already described.* This is followed by a large, but short, and perfectly straight intestine. These organs in the pupa (Fig. 327) have undergone considerable modifications, the whole canal, but more especially the stomach, being contracted both in length and width:† the shortening of the intestine not being in proportion to that of the whole body, requires its being folded upon itself for a certain extent. In the moth, (Fig. 328,) the contraction of the stomach has proceeded much farther; and an additional cavity, which may be considered as a species of crop or gizzard (G,) is developed: the small intestine takes a great many turns during its course, and a large pouch, or *cæcum*, has been formed at the part where it joins the large intestine.

The hepatic vessels are exceedingly numerous in the Crustacea, occupying a very large space in the general cavity; and they compose by their union an organ of considerable size, which may be regarded as analogous in its functions to

* See the figures and description of those of the Nais and the leech, p. 77 and 78.

† Carus states that he found the stomach of a pupa, twelve days after it had assumed that state, scarcely half as long, and only one-sixth as wide as it had been in the caterpillar.

the Liver of the higher classes of animals. This organ acquires still greater size and importance in the Mollusca, where it frequently envelops the stomach, pouring the bile into its cavity by numerous ducts.* As the structure and course of the intestinal canal varies greatly in different tribes of Mollusca, they do not admit of being comprised in any general description. The only examples I think it necessary to give in this class, are those of the *Patella*, or Limpet, and of the *Pleurobranchus*. The intestinal tube of the Patella is delineated in Fig. 329; where M is the mouth; T, the tongue folded back; O, the œsophagus; and S, the stomach, from which the tortuous intestinal tube is seen to be continued. All the convolutions of this tube, as well as the stomach itself, are enclosed, or rather imbedded, in the substance of the liver, which is the largest organ of the body.

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The *Pleurobranchus Peronii* (Cuv.) is remarkable for the number and complication of its organs of digestion. They are seen laid open in Fig. 330; where C is the crop; G, the gizzard; P, a plicated stomach, resembling the third stomach of ruminant quadrupeds; and D, a fourth cavity, being that in which digestion is completed. A canal of communication is seen at T, leading from the crop to this last cavity: B is the point where the biliary duct enters.

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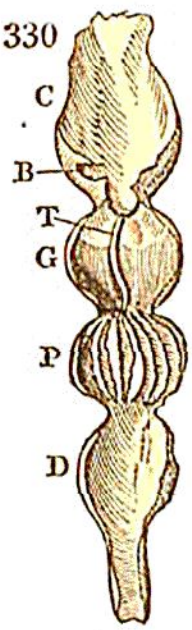

In the Cephalopoda, the structure of these organs is very complicated; for they are provided with a crop, a muscular gizzard, and a cæcum, which has a spiral form. In these animals we also discover the rudiment of another auxiliary organ, namely, the *Pancreas*, which secretes a fluid contri-

* Transparent crystalline needles, the nature and uses of which are quite unknown, are frequently found in the biliary ducts of this class of animals.

buting to the assimilation of the food. This organ becomes more and more developed as we ascend in the scale of animals, assuming a glandular character, and secreting a watery fluid, which resembles the saliva, both in its sensible and chemical properties. It has been conjectured that many of the vessels which are attached to the upper portion of the alimentary canal of insects, and have been termed hepatic, may, in fact, prepare a fluid having more of the qualities of the pancreatic than of the biliary secretion.

The alimentary canal of fishes is in general characterized by being short; and the continuity of the stomach with the intestines is often such as to offer no well marked line of distinction between them. The cœca are generally large and numerous; and a number of tubular organs, connected more especially with the pylorus, and called therefore the *pyloric appendices*, are frequently met with, resembling a cluster of worms, and having some analogy, in situation at least, to the hepatic or pancreatic vessels of insects. Their appearance in the *Salmon* is represented at P, in Fig. 331. The pancreas itself is only met with, in this class of animals, in the order of cartilaginous fishes, and more especially in the Ray and the Shark tribes. A distinct gall-bladder, or reservoir, is also met with in some kinds of fish, but is by no means general in that class.

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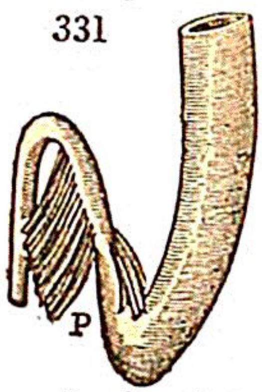


In the classes both of Fishes and of Reptiles, which are cold-blooded animals, the processes of digestion are conducted more slowly than in the more energetic systems of Birds and of Mammalia; and the comparative length of the canal is, on the whole, greater in the former than in the latter: but the chief differences in this respect depend on the kind of food which is consumed, the canal being always shortest in those tribes that are most carnivorous.* As the Frog, in the different stages of its growth,

* See Home, Lectures, &c. I. 401.

lives upon totally different kinds of food, so we find that the structure of its alimentary canal, like that of the moth, undergoes a material change during these metamorphoses. The intestinal canal of the tadpole is of great length, and is collected into a large rounded mass, composed of a great number of coils, which may easily be distinguished, by the aid of a magnifying glass, through the transparent skin. During its gradual transformation into a frog, this canal becomes much reduced in its length; so that when the animal has attained its perfect form, it makes but a single convolution in the abdominal cavity.

A similar correspondence exists between the length of the canal, and the nature of the food in the class of Birds. At the termination of the small intestine there are usually found two cæca, which, in the gallinaceous and the aquatic fowls, are of great length: those of the ostrich contain in their interior a spiral valve. Sir E. Home is of opinion that in these animals the functions of the pyloric portion of the stomach are performed by the upper part of the intestine.

In the intestines of the Mammalia contrivances are employed with the apparent intention of preventing their contents from passing along too hastily: these contrivances are most effectual in animals whose food is vegetable, and contains little nourishment, so that the whole of what the food is capable of yielding is extracted from them. Sir E. Home observes that the colon, or large intestine of animals which live upon the same species of food, is of greater length, in proportion to the scantiness of the supply. Thus, the length of the colon of the Elephant, which inhabits the fertile woods of Asia, is only 26½ feet; while, in the Dromedary, which dwells in the arid deserts of Arabia, it is 42 feet. This contrast is still more strongly marked in birds. The Cassowary of Java, which lives amidst a most luxuriant supply of food, has a colon of one foot in length, and two cæca, each of which is six inches long, and one quarter of an inch in diameter. The African ostrich, on the other hand, which inhabits a country where the supply of food is very scanty, has the colon forty-five feet long; each of the cæca is two feet nine inches in length, and, at the widest part, three inches in diameter; in addition to which, there are broad valves in the interior of both these cavities.*

On comparing the structure of the digestive organs of Man with those of other animals belonging to the class Mammalia, we find them holding a place in the series intermediate between those of the purely carnivorous, and exclusively herbivorous tribes, and, in some measure, uniting the characters of both. The powers of the human stomach do not, indeed, extend to the digestion either of the tough woody fibres of vegetables, on the one hand, or the compact texture of bones on the other; but, still, they are competent to extract nourishment from a wider range of alimentary substances, than the digestive organs of almost any other animal. This adaptation to a greater variety of food may also be inferred from the form and disposition of the teeth, which combine those of different kinds more completely than in most mammalia, excepting, perhaps, the Quadrumana, in which, however, the teeth do not form, as in man, an uninterrupted series in both jaws. In addition to these peculiarities, we may also here observe, that the sense of taste, in the human species, appears to be effected by a greater variety of objects than in the other races of animals. All these are concurring indications that nature, in thus rendering man omnivorous, intended to qualify him for maintaining life wherever he could procure the materials of subsistence, whatever might be their nature, whether animal or vegetable, or a mixture of both, and in whatever soil or climate they may be produced; and for endowing him with the power of spreading his race, and extending his dominion

* Lectures, &c. I. 470. In the account above given of the digestive organs I have purposely omitted all mention of the spleen; because, although this organ is probably in some way related to digestion, the exact nature of its functions has not yet been determined with any certainty.

over every accessible region of the globe. Thus, then, from the consideration of the peculiar structure of the vital as well as the mechanical organs of the human frame, may be derived additional proofs of their being constructed with reference to faculties of a higher and more extensive range than those of any, even the most favoured species of the brute creation.

CHAPTER IX.

LACTEAL ABSORPTION.

The Chyle, of which we have now traced the formation, is a fluid of uniform consistence, perfectly bland and unirritating in its properties, the elements of which have been brought into that precise state of chemical composition which renders them fit to be distributed to every part of the system for the purposes of nourishment. In all the lower orders of animals it is transparent; but the chyle of mammalia often contains a multitude of globules, which give it a white colour, like milk. Its chemical composition appears to be very analogous to that of the blood into which it is afterwards converted. From some experiments made by my late much valued friend Dr. Marcet, it appears that the chyle of dogs, fed on animal food alone, is always milky, whereas, in the same animals, when they are limited to a vegetable diet, it is nearly transparent and colourless.*

The chyle is absorbed from the inner surface of the intestines by the *Lacteals*, which commence by very minute orifices, in incalculable numbers, and unite successively into larger and larger vessels, till they form trunks of considerable size. They pass between the folds of a very fine and delicate membrane, called the *mesentery*, which connects the intestines with the spine, and which appears to be interposed in order to allow them that degree of freedom of motion, which is so necessary to the proper performance of their functions. In the mesentery, the lacteals pass through several glandular bodies, termed the *mesenteric glands*, where it is probable that the chyle undergoes some modification, preparatory to its conversion into blood.

* Medico-Chirurgical Transactions, vi. 630.

The mesenteric glands of the Whale contain large spherical cavities, into which the trunks of the lacteals open, and where the chyle is probably blended with secretions proper to those cavities; but no similar structure can be detected in terrestrial mammalia.

It is only among the Vertebrata that lacteal vessels are met with. Those of Fishes are simple tubes, either wholly without valves, or if their be any, they are in a rudimental state, and not sufficiently extended to prevent the free passage of their fluid contents in a retrograde direction. The lacteals of the Turtle are larger and more distinct than those of fishes, but their valves are still imperfect, though they present some obstruction to descending fluids. In Birds and in Mammalia these valves are perfectly effectual, and are exceedingly numerous, giving to the lacteals, when distended with fluid, the appearance of strings of beads. The effect of these flood-gates, placed at such short intervals, is that every external pressure made upon the tube, assists in the propulsion of the fluid in the direction in which it is intended to move. Hence it is easy to understand how exercise must tend to promote the transmission of the chyle. The glands are more numerous and concentrated in the Mammalia, than in any other class.

From the mesenteric glands the chyle is conducted, by the continuation of the lacteals, into a reservoir, which is termed the *receptacle of the chyle;* whence it ascends through the *thoracic duct*,* which passes along the side of the spine, in a situation affording the best possible protection from injury or compression, and opens into the great veins leading directly into the heart.

In invertebrated animals having a circulatory system of vessels, the absorption of the chyle is performed by veins instead of lacteal vessels.

The sanguification of the chyle, or its conversion into blood, takes place, during the course of the circulation, and

* This duct is occasionally double.

is principally effected by the action of atmospheric air in certain organs, hereafter to be described, where that action, or *aeration* as it may be termed, in common with an analogous process in vegetables, takes place. In all vertebrated animals the blood has a red colour, and it is also red in most of the Annelida; but in all other invertebrated animals, it is either white or colourless.* We shall, for the present, then, consider it as having undergone this change, and proceed to notice the means employed for its distribution and circulation throughout the system.

* Vauquelin has observed that chyle has often a red tinge in animals.

CHAPTER X.

Circulation.

§ 1. *Diffused Circulation.*

Animal life, implying mutual actions and reactions between the solids and fluids of the body, requires for its maintenance the perpetual transfer of nutritive juices from one part to another, corresponding in activity to the extent of the changes which are continually taking place in the organized system. For this purpose we almost constantly find that a circulatory motion of the nutrient fluids is established; and the function which conducts and regulates their movements is emphatically denominated *the Circulation*. Several objects of great importance are answered by this function; for, in the first place, it is through the circulation that every organ is supplied with the nutritive particles necessary for its development, its growth, and its maintenance in a healthy condition; and that the glands, in particular, as well as the other secreting organs, are furnished with the materials they require for the elaboration of the products, which it is their peculiar office to prepare. A second essential object of the circulation, is to transmit the nutritive juices to certain organs, where they are to be subjected to the salutary influence of the oxygen of the atmosphere; a process which in all warm-blooded animals, combined with the rapid and extensive distribution of the blood, diffuses and maintains throughout the system the high temperature required by the greater energy of their functions. Hence it necessarily follows that the particular mode in which the circulation is conducted in each respective tribe of animals, must influence every other function of their economy, and must, therefore, constitute an essential element in determining their physiological condition. We find, accordingly, that among the characters on which systematic zoologists have founded their great divisions of the animal kingdom, the utmost importance is attached to those derived from differences of structure in the organs of circulation.

A comprehensive survey of the different classes of animals with reference to this function, enables us to discern the existence of a regular gradation of organs, increasing in complexity as we ascend from the lower to the higher orders; and showing that here, as in other departments of the economy of nature, no change is made abruptly, but always by slow and successive steps. In the very lowest tribes of Zoophytes, the modes by which nutrition is accomplished can scarcely be perceived to differ from those adopted in the vegetable kingdom, where, as we have already seen, the nutritive fluids, instead of being confined in vessels, appear to permeate the cellular tissue, and thus immediately supply the solids with the materials they require; for, in the simpler kinds of Polypi, of Infusoria, of Medusæ, and of Entozoa, the nourishment which has been prepared by the digestive cavities is apparently imbibed by the solids, after having transuded through the sides of these organs, and without its being previously collected into other, and more general cavities. This mode of nutrition, suited only to the torpid and half vegetated nature of zoophytes, has been denominated *nourishment by imbibition*, in contradistinction to that by *circulation;* a term which, as we have seen, implies, not merely a system of canals, such as those existing in Medusæ, where there is no evidence of the fluids really circulating, but an arrangement of ramified vessels, composed of membranous coats, through which the nutrient fluid moves in a continued circuit.

The distinction which has thus been drawn, however, is one on which we should be careful not to place undue reliance, for it is founded, perhaps, more on our imperfect means of investigation, than on any real differences in the procedures of nature relative to this function. When the juices either of plants, or of animals, are transparent, their motions are imperceptible to the eye, and can be judged of only by other kinds of evidence; but when they contain globules, differing in their density from that of the fluid, and therefore capable of reflecting light, as is the case with the sap of the *Chara* and *Caulinia*, we have ocular proof of the existence of currents, which as long as the plant is living and in health, pursue a constant course, revolving in a regular and defined circuit; and all plants which have milky juices exhibit this phenomenon. Although the extent of each of these vegetable currents is very limited, compared with the entire plant, it still presents an example of the tendency which the nutrient fluids of organized structures have to move in a circuit, even when not confined within vessels or narrow channels; for this movement of *rotation*, or *cyclosis*, as it has been termed,* whatever may be its cause, appears always to have a definite direction. The current returns into itself, and continues without intermission, in a manner much resembling the rotatory movements occasionally produced in fluids by electro-magnetism.†

Movements, very similar in their appearance and character to those of vegetable cyclosis, have been recently discovered in a great number of polypiferous Zoophytes, by Mr. Lister, who has communicated his observations in a paper which was lately read to the Royal Society, and of which the following are the principal results. In a specimen of the *Tubularia indivisa*, when magnified one hundred times, a current of particles was seen within the tubular stem of the polype, strikingly resembling, in the steadiness and continuity of its stream, the vegetable circulation in the Chara.

* See pages 41 and 42 of this volume.

† So great is this resemblance, that it has led several physiologists to ascribe these movements to the agency of electricity; but there does not, as yet, appear to be any substantial foundation for this hypothesis.

Its general course was parallel to the slightly spiral lines of irregular spots on the surface of the tube, ascending on the one side, and descending on the other; each of the opposite currents occupying one-half of the circumference of the cylindric cavity. At the knots, or contracted parts of the tube, slight eddies were noticed in the currents; and at each end of the tube the particles were seen to turn round, and pass over to the other side. In various species of *Sertulariæ* the stream does not flow in the same constant direction; but, after a time, its velocity is retarded, and it then either stops, or exhibits irregular eddies, previous to its return in an opposite course; and so on alternately, like the ebb and flow of the tide. If the currents be designedly obstructed in any part of the stem, those in the branches go on without interruption, and independently of the rest. The most remarkable circumstance attending these streams of fluid is that they appear to traverse the cavity of the stomach itself, flowing from the axis of the stem into that organ, and returning into the stem without any visible cause determining these movements. Similar phenomena were observed by Mr. Lister in *Campanulariæ* and *Plumulariæ*.

In some of the minuter species of Crustacea the fluids have been seen, by the aid of the microscope, moving within the cavities of the body, as if by a spontaneous impulse, without the aid of a propelling organ, and apparently without being confined in membranous channels, or tubes of any sort. This kind of diffused circulation is also seen in the embryos of various animals, at the earliest periods of their development, and before any vessels are formed.

§ 2. *Vascular Circulation.*

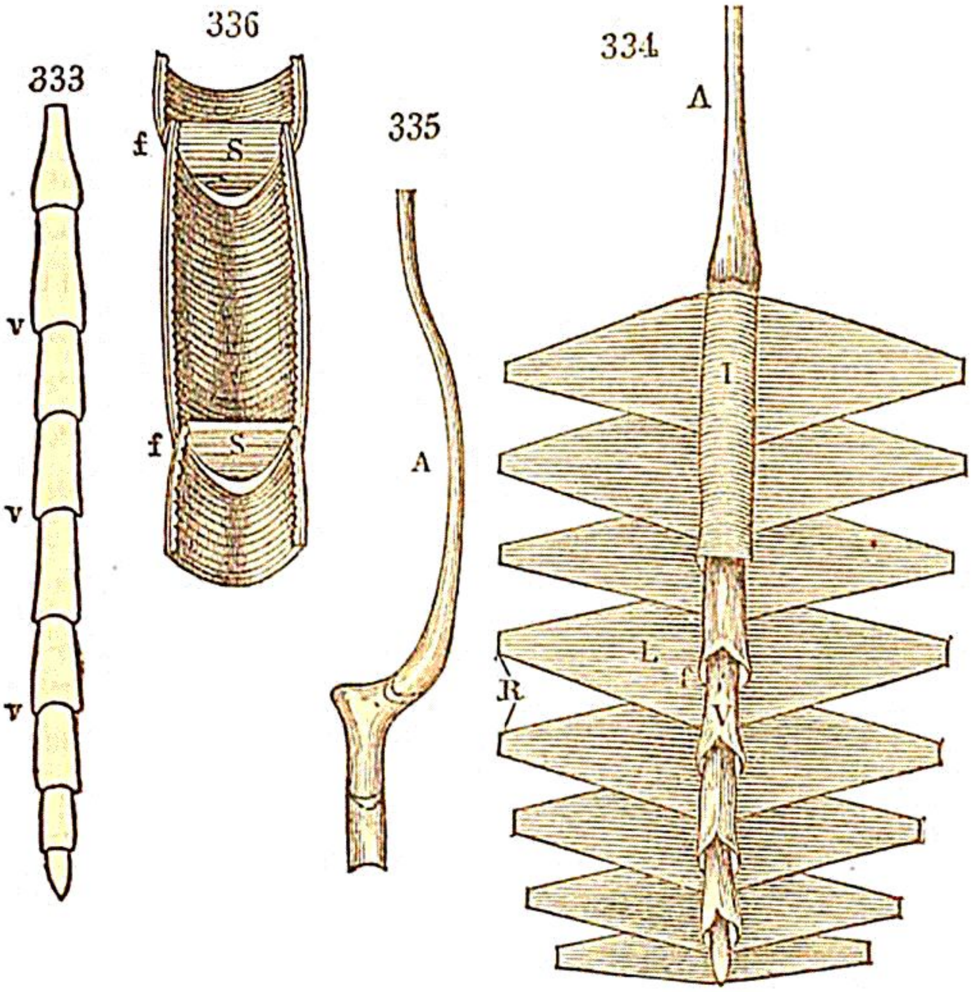
The next step in the gradation of structures consists in the presence of vessels, within which the fluids are confined, and by which their course and their velocity are regulated;

and, in general, these vessels form a complete circuit. The first rudiments of a vascular organization are those observed and described by Tiedemann, in the *Asteriæ*, which are situated higher in the animal scale than Medusæ; but whether any actual circulation takes place in the channels constituted by these vessels, which communicate both with the cavity of the intestine, and with the respiratory organs, is not yet determined with any certainty. The *Holothuriæ*, which also belong to the order of Echinodermata, are furnished with a complex apparatus of vessels, of which the exact functions are still unknown. In those species of Entozoa which exhibit a vascular structure, the canals appear rather to be ramifications of the intestinal tube, than proper vessels, for no distinct circulation can be traced in them: an organization of this kind has already been noticed in *Tæniæ*.*

It was, till very lately, the prevailing opinion among naturalists that all true insects are nourished by imbibition, and that there exists in their system no real vascular circulation of juices. In all the animals belonging to this class, and in every stage of their development, there is found a tubular organ, called the *dorsal vessel*, extending the whole length of the back, and nearly of uniform diameter, except where it tapers at the two ends. It contains a fluid, which appears to be undulated backwards and forwards, by means of contractions and dilatations, occurring in succession in different parts of the tube; and it is also connected with transverse ligamentary bands, apparently containing muscular fibres, capable, by their action, of producing, or, at least, of influencing these pulsatory movements. An enlarged representation of the dorsal vessel of the *Melolontha vulgaris*, or common cockchaffer, isolated from its attachments, is given in Fig. 333, showing the series of dilatations (v, v, v) which it usually presents in its course; and in Fig. 334, the same vessel is exhibited in connexion with the ligamentary

* Page 64, in this volume, Fig. 247. The family of *Planariæ* present exceptions to this general rule: for many species possess a system of circulating vessels. See Dugès, Annales des Sciences Naturelles, xv. 161.

and muscular apparatus which surrounds it, seen from the lower side. In the last of these figures, A is the tapering



prolongation of the tube, proceeding towards the head of the insect; v, one of the dilated portions, or ventricles, as they have been called, of the dorsal part of the tube; f, one of the small tendinous folds, to which the ligamentary bands are attached; and L is one of these bands, having a triangular, or, if considered as continuous with that on the other side of the vessel, a rhomboidal shape, and attached at R, to the superior segments of the abdomen. At I is seen a layer of the same fibres, which are partly ligamentous and partly muscular, passing underneath the dorsal vessel, and forming, in conjunction with the layer that passes above it, a sheath, which embraces and fixes that vessel in its place: these inferior layers have been removed from the other parts of the vessel, to allow the upper layers to be seen, as is the case at

L. Fig. 335 gives a side view of the anterior extremity of the same vessel, showing the curve (A) which it describes as it bends downwards in its course towards the head.

The function performed by the dorsal vessel, which, judging from the universal presence of this organ in insects, must be one of great importance in their economy, was long a profound mystery. Its analogy in structure and position to the dorsal vessels of the Arachnida and the Annelida, where it evidently communicates with channels of circulation, and exhibits movements of pulsation resembling those of insects, was a strong argument in favour of the opinion that it is the prime mover of a similar kind of circulation; but then, again, this hypothesis appeared to be overturned by the fact that no vessels of any kind could be seen extending from it in any direction; nor could any channels for the transmission of a circulating fluid be detected in any part of the body. Those organs, which, in animals apparently of an inferior rank, are most vascular, such as the stomach, the intestinal tube, the eye, and other apparatus of the senses, seemed to be constructed, and to be nourished, by means totally different from those adopted in the former animals. Although extremely minute ramifications of air tubes are every where visible in the interior of insects, yet, neither Cuvier, nor any other anatomist, could succeed, by the closest scrutiny, in detecting the least trace of blood vessels; and the presumption, therefore, was, that none existed.

But it still remained a question, if the dorsal vessel be not subservient to circulation, what is its real function? Marcel de Serres, who bestowed great pains in investigating this subject, came to the conclusion that its use is to secrete the fatty matter, which is generally found in great abundance in the abdominal cavity, and which is accumulated particularly around the dorsal vessel.* A more attentive examination of the structure of the vessel itself brought to light a valvular apparatus, of which the only con-

* See his various papers in the Mémoires du Muséum d'Hist. Nat.; tom. iv. and v.

ceivable purpose is that of determining the motion of the contained fluid in one constant course; a purpose necessarily incompatible with its supposed alternate undulation in opposite directions, from one end of the tube to the other. These valves are exhibited in Fig. 336, in a still more magnified view of a longitudinal section of the dorsal vessel, showing the semicircular folds (s, s) of its inner membrane, which perform the function of valves by closing the passage against any retrograde motion of the fluid. This discovery of valves in the dorsal vessel, again made the balance of probability incline towards the opinion that it is the agent of some kind of circulation.

All doubt as to the reality of a circulation in insects is now dispelled by the brilliant discoveries of Professor Carus, who, in the year 1824, first observed this phenomenon in the larva of the *Agrion puella*. In the transparent parts of this insect, as well as of many others, numerous streams of fluid, rendered manifest by the motions of the globules they contain, are seen meandering in the spaces which intervene between the layers of the integument, but without appearing to be confined within any regular vessels. The streams on the sides of the body all pass in a direction backwards from the head, till they reach the neighbourhood of the posterior end of the dorsal vessel, towards which they all converge; they are then seen to enter that vessel, and to be propelled by its pulsations towards its anterior extremity, where they again issue from it, and are subsequently divided into the scattered streams, which descend along the sides of the body, and which, after having thus completed their circuit, return into the pulsating dorsal vessel.

This mixed kind of circulation, partly diffused and partly vascular, is beautifully seen in the larva of the *Ephemera marginata*,* where besides the main current, which, after

* This insect is figured and described in Dr. Goring and Mr. Pritchard's "Microscopic Illustrations," and its circulation is very fully detailed, and illustrated by an engraving on a large scale, by Mr Bowerbank, in the Entomological Magazine, i. 239; plate ii.

being discharged from the anterior extremity of the dorsal vessel, descends in a wide spreading stream on each side, and beneath that vessel another portion of the blood is conveyed by two lateral trunks, which pass down each side of the body, in a serpentine course, and convey it into the lower extremity of the dorsal vessel, with which they are continuous. These are decidedly vessels, and not portions of the great abdominal cavity, for their boundaries are clearly defined; yet they allow the blood contained in them to escape into that cavity, and mix with the portion previously diffused. All these wandering streams sooner or later find their way into the dorsal vessel, being absorbed by it at various points of its course, where its membranous coat is reflected inwards to form the valves. In the legs, the tail, and the antennæ, the circulation is carried on by means of vessels, which are continuous with the lateral vessels of the body, branching off from them in the form of loops, ascending on one side, and then turning back to form the descending vessel, so that the currents in each, move in contrary directions. Fig. 337 represents the appearance of

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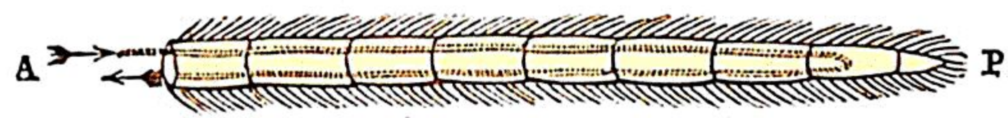

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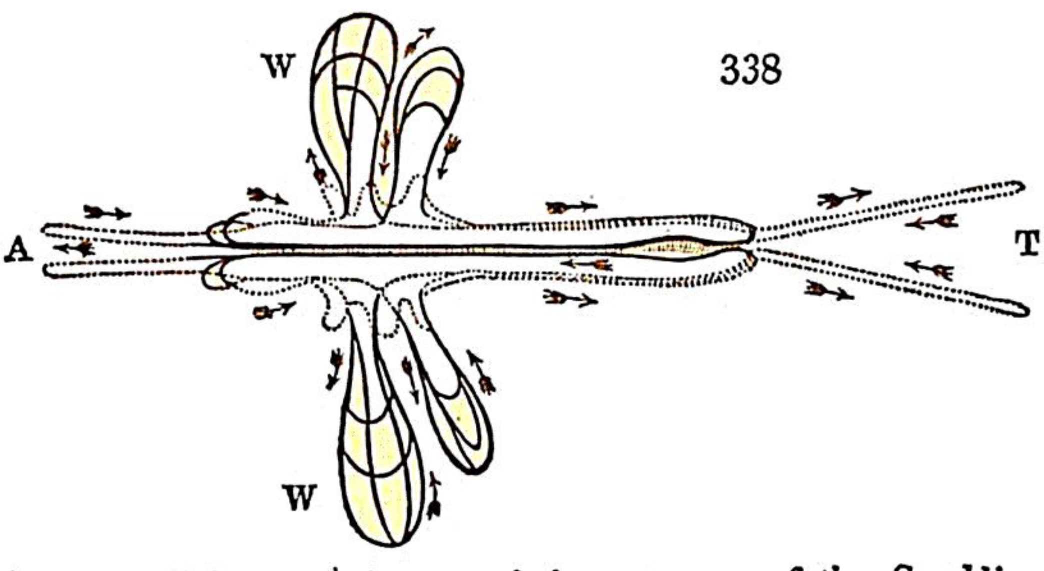

these parallel vessels in one of the antennæ of the *Semblis viridis*, magnified thirty times its natural size. The whole system of circulating vessels in that insect, of which the former is only a detached part, is shown in Fig. 338, where the course of the blood is indicated by arrows; A, representing the currents in the antennæ; W, those in the rudimental wings; and T, those in the tail; in all which parts the vessels form loops, derived from the main vessels of the trunk. In some larvæ the vascular loops, conveying these collateral streams, pass only for a certain distance into the legs; sometimes, indeed, they proceed no farther than the haunches. The currents of blood in these vessels have not a uniform velocity, being accelerated by the impulsions they receive from the contractions of the dorsal vessel, which appears to be the prime agent in their motion.

As the insect advances to maturity, and passes through its metamorphoses, considerable changes are observed to take place in the organization of the circulating system, and in the energy of the function it performs. The vessels in the extreme parts, as in the tail, are gradually obliterated, and the circulation in them, of course, ceases, the blood appearing to retire into the more internal parts. In the wings, on the other hand, where the development proceeds rapidly the circulation becomes more active; and even after they have attained their full size, and are yet in a soft state, the motion of the blood in the centre of all the nervures is distinctly visible:* but afterwards, as the wings become dry, it ceases there also, and is then confined to the vessels of the trunk. In proportion as the insect approaches to the completion of its development, these latter vessels also, one after the other, shrink and disappear, till, at length, nothing which had once appertained to this system remains visible, except the dorsal vessel. But, as we observe this vessel still continuing its pulsatory movements, we may fairly infer that they are designed to maintain some degree of obscure and imperfect circulation of the nutrient juices, through vessels,

* These currents in the wing of the *Semblis bilineata* have been described and delineated by Carus, in the Acta Acad. Cæs. Leop. Carol. Nat. Cur. vol. xv. part ii. p. 9.

which may, in their contracted state, corresponding to the diminished demands of the system, have generally escaped detection. In conformation of these views, it may be stated, that several observers have at length, succeeded in tracing minute branches, proceeding in different directions, from the dorsal vessel, and distributed to various organs. The division of the anterior part of the dorsal vessel into descending branches was noticed by Comparetti. Dugès has observed a similar division of this vessel in the corselet of several species of *Phalenæ*, and farther ramifications in that of the *Gryllus lineola:* and Audouin has traced them in many of the Hymenoptera.*

* Annales des Sciences Naturelles, xv. 308.

The figures which follow (from 339 to 345) are representations, of the natural size, of the dorsal vessel of the *Sphinx ligustri*, or Privet Hawk-moth, which has been dissected in its three different stages, with great care, by Mr. Newport, from whose drawings these figures have been engraved, and to whom I am indebted also for the description which follows:—

The dorsal vessel of this insect is an elongated and gradually tapering ves-

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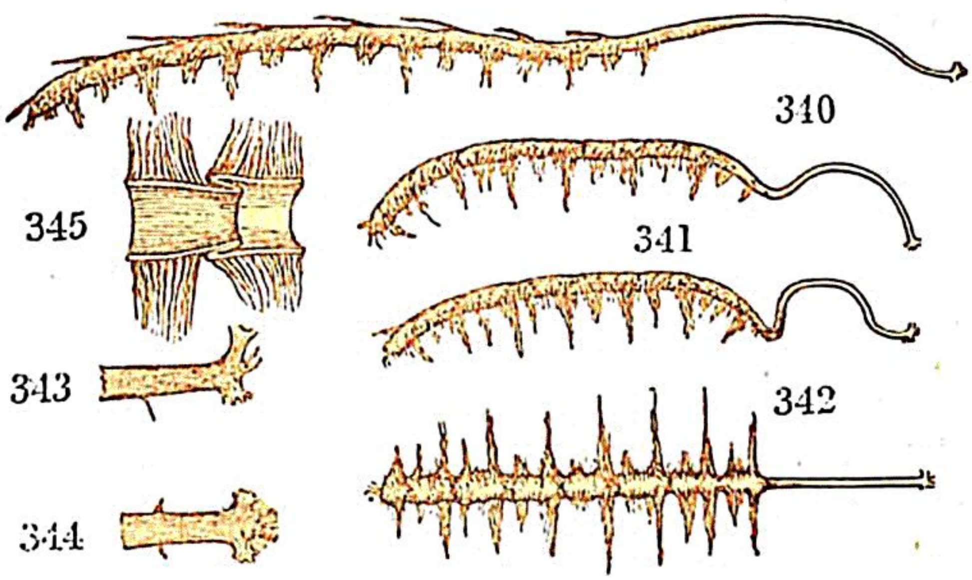

sel, extending from the hinder part of the abdomen, along the back, towards the head; and furnished with valves, which correspond very nearly in their situation to the incisions of the body. During the changes of the insect from the larva to the imago state, it undergoes a slight modification of form. In every state it may be distinguished into two portions, a *dorsal* a d an *aor-*

The discovery of the circulation in insects, and of its varying energy at different periods of growth, has elucidated many obscure points in the physiology of this important

tal. The dorsal portion, which is the one in which a pulsation is chiefly observable, is furnished with distinct valves, is attached along the dorsal part of the body by lateral muscles, and has vessels which enter it laterally, pouring into it the circulating fluid, which is returning from the sides and inferior portions of the body. In the caterpillar, this portion of the dorsal vessel extends from the twelfth to the anterior part of the fifth segment. It is furnished with eight double valves, which are formed, as Mr. Bowerbank has correctly described them in the *Ephemera marginata*—namely, the upper valve "by a reflecting inwards and upwards of the inner coat, or coats of the artery," (by which he means the dorsal vessel) "and the under one by a contraction or projection of the like parts of a portion of the artery beneath, so as to come within the grasp of the lower part of the valve above it." The whole vessel is made up of three coats, the two innermost of which, the lining, or serous, and the muscular, or principal portion of the vessel, constitute the reflected portions, or valves; while the third, or outermost coat, which is exceedingly thin and delicate, is continued over the vessel nearly in a straight line, and does not appear at all to follow the reflexions of the other two. In the caterpillar, this portion of the vessel has eight pairs of small suspensory muscles, seen along the upper side of Fig. 339, which arise from the middle of the upper surface of each valve, and are continued back to be attached over the middle of the next valve: they seem to have considerable influence over the contractions of the valves. The Aortal, or anterior portion of the vessel, extends from the hinder part of the fourth segment to its termination and division into vessels, to be distributed to the head, which division takes place after it has passed the œsophagus, and at a point immediately beneath the supra-œsophageal ganglion, or brain of the insect. This portion of the vessel is much narrower than the dorsal, has no distinct valves or muscles; nor do any vessels enter it laterally; but it is very delicate and transparent, and gradually diminishes in size from its commencement to its anterior termination. Its course, in the caterpillar, is immediately beneath the integument, along the fourth and third segments, till it arrives at the hinder parts of the second segment; when it gradually descends upon the œsophagus, and immediately behind the cerebral ganglion, gives off a pair of exceedingly minute vessels. It then passes beneath the ganglion, and, in the front part of the head, is divided into several branches, as noticed by Mr. Newport in the anatomical description he has given of the nerves of this species of Sphinx: (Phil. Trans. 1832, p. 385.) These branches are best observed in the chrysalis (Fig. 340:) in all the stages they may be divided into three sets; the first is given off immediately after the vessel has passed beneath the ganglion; and consists of two lateral trunks, the united capacity of class. It explains why insects, after they have attained their imago state, and the circulation is nearly obliterated, no longer increase in size, and require but little nourishment for the maintenance of life. This, however, is a state not calculated for so long a duration as that in which the development is advancing; and, accordingly, the period during which the insect remains in the imago condition is generally short, compared to that of the larva, where a large supply of nutriment, and a rapid circulation of the fluids, concur in maintaining the vital functions in full activity. Thus, the Ephemera, which lives for two or three years in the larva state generally perishes in the course of a few hours after it has acquired wings, and reached its perfect state of maturity.

which is equal to about one-third of that of the aorta; they descend, one on each side of the mouth, and are each divided into three branches. The second set consists of two pairs of branches, one going apparently to the tongue, the other to the antennæ. The third set is formed by two branches, which pass upwards, and are the continuations of the aorta; they divide into branches, and are lost in the integuments, and structures of the anterior part of the head.

The pulsatory action of the dorsal vessel is continued along its whole course, and seems to terminate at the division of the vessel into branches. During the metamorphosis of the insect, this vessel becomes considerably shortened, but is stronger and more consolidated in its structure. Its course is likewise altered; from having, in the caterpillar, (Fig. 339,) passed along, nearly in a straight line, it begins in the chrysalis, (Fig. 340,) to descend in the fifth segment, and to pass under what is to become the division between the thorax and abdomen in the perfect insect. It then ascends in the fourth segment, and descends again in the second, so that when the insect has attained its perfect form, (Fig. 341,) its course is very tortuous. The vessels which enter it are situated in the abdomen, and pass in laterally among the muscles, chiefly at the anterior part of each segment or valve. Fig. 342 is a superior, or dorsal view of the same vessel, in the perfect state of the insect, which shows, still more distinctly, the vessels entering it laterally, intermixed with the lateral muscles. Fig. 343 is a magnified lateral view of the anterior extremity of the dorsal vessel, corresponding to Fig. 341; and Fig. 344, a similarly magnified view of the same portion of the vessel seen from above, corresponding to Fig. 342. Fig. 345 shows the mode in which the valves are formed by a duplicature of the inner membrane in the perfect insect.

In proportion as the changes of form which the insect undergoes are less considerable, the evidences of a circulation become more distinct. Such is the case in many of the Apterous Insects, composing the family of *Myriapoda:* in the *Scolopendra morsitans*, (Linn.,) for instance, Dugès observed the dorsal, vessel dividing into three large branches.

Most of the tribes belonging to the class of Arachnida have, likewise, a dorsal vessel, very analogous in its structure and situation to that of insects; and, as none of them undergo any metamorphosis, their vascular system admits of being considerably developed, and becomes a permanent part of the organization. Fig. 346 shows the dorsal vessel of the *Aranea domestica* or house spider, with some of the arterial trunks arising from it, lying embedded in a thick mass of substance, having a similar oily character to that which is contained, in large quantities, in the principal cavities of insects. It is, in general, difficult to obtain a view of the circulation in the living spider, on account of the thick covering of hair which is spread over the body and the limbs; but if a species, which has no hair, be selected for examination, we can see very distinctly, through the microscope, the motion of the blood in the vessels, by means of the globules it contains, both in the legs and in other parts, where it presents appearances very similar to those already described in the limbs of the larvæ of insects.

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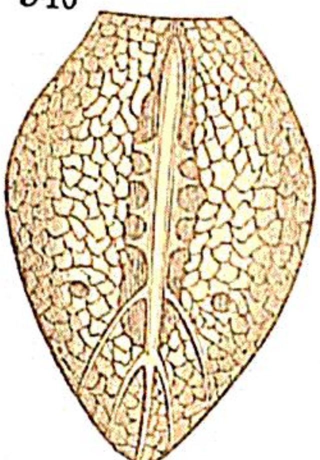

A complete vascular circulation is established in all the animals which compose the class of Annelida; the vessels being continuous throughout, and having sufficient power to propel the blood through the whole of its circuit. Great variety exists in the arrangement and distribution of these vessels, depending on the form of the animal, the complication of its functions, and the extent of its powers. The first rudiment of a distinct system of circulating vessels, independent of the ramified tubes proceeding from the intestinal canal, occurs in the *Planariæ*, which are a tribe of flat vermiform animals, in many respects allied to the more developed Entozoa, and appearing placed as an intermediate

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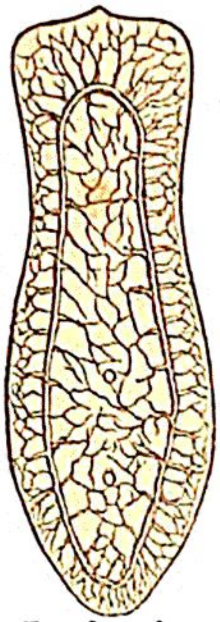

link between them and the Annelida. In many species such as the *Planaria nigra*, *fusca*, and *tremellaris*, (*Muller*,) Dugès observed two longitudinal trunks (Fig. 346*) running along the sides of the under surface of the animal, and joining together, both at their fore and hind extremities, so as to form a continuous channel of an oval form.† A great number of smaller vessels branch off from these main trunks in every direction, and ramify extensively, often uniting with those from the opposite side, and establishing the freest communications between them.

In the Annelida which have a more lengthened and cylindric form, the principal vessels have a longitudinal course, but are differently disposed in different species. There is, in all, a vascular trunk, extending along a middle line, the whole length of the back, and especially designated as the *dorsal vessel:* in general, there is also a corresponding trunk, occupying the middle line of the lower, or abdominal side of the body, and termed the *abdominal vessel.* This latter vessel is sometimes double; one being superficial, and another lying deeper; the principal nervous cord, and chain of ganglia being situated between them. Frequently, there are found, in addition to these, vessels which run along the sides of the body, and are therefore called the *lateral vessels.* In every case there are, as we have seen in the Planaria, numerous branches, and collateral communications between the lateral, the abdominal, and dorsal vessels; more especially at the two extremities of the body, where the great mass of blood, which has been flowing in one direction in one set of vessels, is transferred into others, which convey

† De Blainville has described a structure similar to this in a Planaria from Brazil. Dict. des Sc. Nat. t. xli. 216.

it in the contrary direction, and complete the circuit of its course. The ramifications and lateral connexions of the minuter branches are often so numerous as to compose a vascular net-work, covering a considerable extent of surface. This general description of the circulatory system is applicable to the tribes of Annelĭda possessing the simplest structure, such as the *Nais*, the *Nereis*, and the *Leech;* genera which include a great variety of species of different shapes and sizes.

Although the vessels themselves may be plainly discerned, it is not so easy to determine the real course which the blood takes while circulating within them; and we accordingly find very great discordance in the reports of different physiologists on this subject. De Blainville asserts that in all the Annelida, the blood in the dorsal vessel is carried backwards, that is, from the head to the tail; a motion, which, of course, implies its return in the contrary direction, in either the lateral or the abdominal vessels. In the Nais, the Nereis, and the Leech, these last vessels are two in number, situated at the sides of the abdominal surface of the body. Carus adds his testimony in favour of this mode of considering the circulation in the Annelida. On the other hand, Spix, Bonnet, Sir Everard Home, and Dugès, describe the course of the blood as quite the opposite of this, and maintain that it moves backwards, or towards the tail, in the abdominal vessels; and forwards, or towards the head, in the dorsal vessel. Morren, who is the latest authority on this subject, gives his testimony in favour of the latter view of the subject, as far as relates to the dorsal vessel of the *Erpobdella vulgaris,** an animal allied to the Leech, and already noticed in the account of the mechanical functions of this tribe:† but he considers the abdominal vessel as performing also the same function of carrying the blood forwards towards the head, and the two lateral vessels as conveying it backwards, thus completing the circuit. This is illustrated by the diagram

* *Hirudo vulgaris.* (Linn.) *Nephelis vulgaris.* (Savigny.)

† Vol. i. p. 195, where a delineation of this animal was given, Fig. 130.

(Fig. 347;) where A is the anterior, and P the posterior extremity of the animal, the dorsal vessel occupying the mid-

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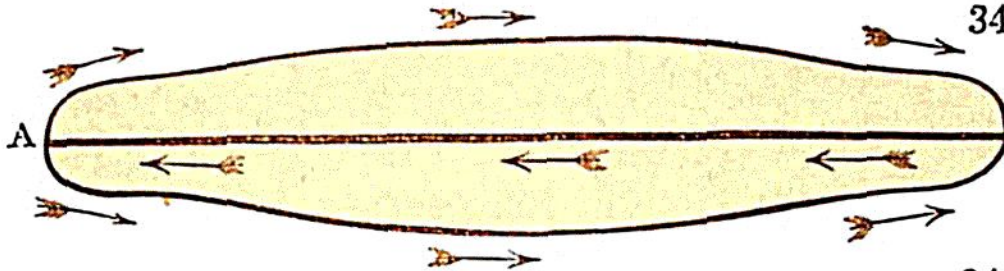

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dle straight line between the two lateral vessels, and the direction of the stream in each being indicated by the adjacent arrows. The blood in the abdominal vessel following the same course as that in the dorsal vessel, the same diagram represents also these vessels seen from below. Fig. 348 is a lower view of the Erpobdella, showing the numerous ramifications of the abdominal vessel; the lesser branches encircling the nervous ganglia, and accompanying the principal nervous filaments which proceed from them; while the lateral vessels are seen pursuing a slightly serpentine course.*

The tribe of *Lumbrici*, which includes the earth-worm,

* Dugès represents the blood of this animal as moving in different directions in the right and in the left lateral vessels; generally backwards in the former, and forwards in the latter: at the same time that it moves backwards in the dorsal, and forwards in the abdominal vessel. In the communicating branches which pass transversely from one lateral vessel to the other, the blood flows from left to right in those situated in the anterior half of the body, and from right to left in those of the posterior half; so that the plane in which its circuit is performed is horizontal, instead of vertical. It is curious to find an example of a similar transverse circulation, in the vegetable kingdom; this has recently been observed by Mr. Solly and Mr. Varley, in a sprout of the *Chara vulgaris*, near the end of which the enclosed fluid revolves continually on its own axis, instead of following the ordinary course of ascent and descent along the sides of the cylindric cavity.—See Trans. of the Society of Arts, xlix. 180.

is distinguished from the annelida already noticed, by being more highly organized, and possessing a more extensive circulation, and a more complicated apparatus for the performance of this function. The greater extent of vascular ramifications appears to require increased powers for carrying the blood through the numerous and intricate passages it has to traverse; and these are obtained by means of muscular receptacles, capable, by their successive contraction, of adding to the impulsive force with which the blood is driven into the trunks that distribute it so extensively. These muscular appendages are globular or oval dilatations of some of the large vascular trunks, which bend round the sides of the anterior part of the body, and establish a free communication between the dorsal and the abdominal vessels. They are described by Dugès as consisting, in the *Lumbricus gigas*, of seven vessels on each side, forming a series of rounded dilatations, about twelve in number, resembling a string of beads.*

In the *Lumbricus terrestris*, or common earth-worm, there are only five pairs of these vessels; they have been described and figured by Sir E. Home:† but the most full and accurate account of their structure has been given by Morren, in his splendid work on the anatomy of that animal.‡ Fig. 349, which is reduced from his plates, represents these

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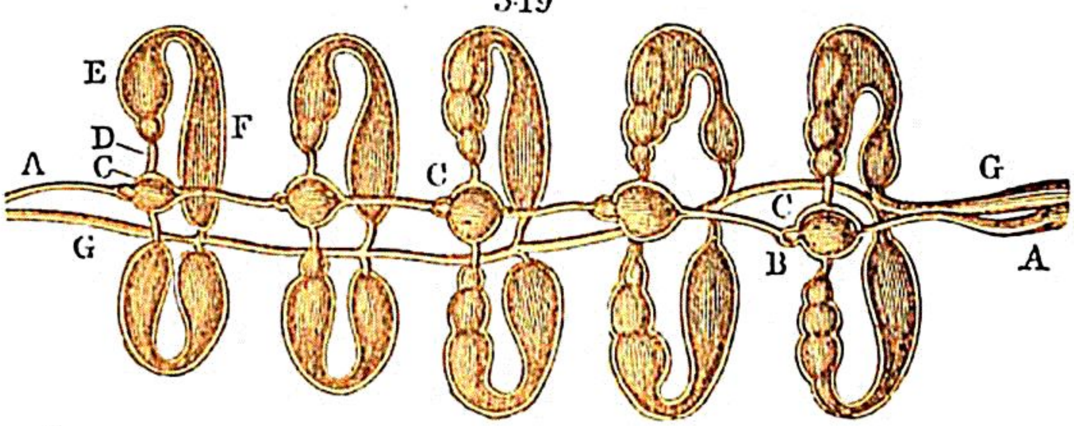

* They are termed by Dugès, *Vaisseaux moniliformes, ou dorso-abdominaux.*—Annales des Sciences Naturelles, xv. 299.

† Philos. Transact. for 1817, p. 3: and Pl. iii. Fig. 4.

‡ "De Lumbrici terrestris Historia naturalis, necnon Anatomia Tractatus." Qto. Bruxelles, 1829.

singular appendages to the vascular system of the earth-worm, separated from their attachments, and viewed in connexion only with the dorsal and abdominal trunks in which they terminate. The abdominal vessel, (A, A,) on arriving near the œsophagus, is dilated at the point B, into a globular bulb (C,) which is followed, at equal intervals, by four others (C, C.) From each of these bulbs, or *ventricles*, as they are termed by Morren, a vessel (D) is sent off at right angles, on each side; this vessel also enlarges into several nearly globular dilatations (E,) followed by a still larger, and more elongated oval receptacle (F,) which completes the semicircular sweep taken by the vessel in bending round the sides of the body, in order to join the dorsal vessel (G, G,) in which all the other four communicating vessels, presenting similar dilatations, terminate. Sir E. Home is of opinion that these dilated portions of the vessel are useful as reservoirs of blood, for supplying it in greater quantity to the neighbouring organs, as occasion may require: but Morren ascribes to them the more important office of accelerating, by their muscular action, the current of circulating blood. If the latter of these views be correct, which the strong pulsations, constantly visible in these bulbs, render extremely probable, this structure would offer the first rudiments of the organ which, in all the superior classes of animals, performs so important an office in the circulation of the blood, namely, the *heart:* and this name, indeed, is given by Cuvier, Morren, and others, to these dilated portions of the vascular systems of the higher orders of Annelida.

Here, also, the statements of different anatomists are at variance, with regard to the direction taken by the blood while circulating in the vessels: Home and Dugès represent it as proceeding forwards in the dorsal, and backwards in the abdominal vessels; a course which implies its descent along the lateral communicating vessels just described; while De Blainville and Morren ascribe to it a course precisely the reverse. Amidst these conflicting testimonies, it is extremely difficult to determine on which side the truth lies; and a suspicion will naturally arise, that the course of the blood in the vessels may not be at all times uniform, but may be liable to partial oscillations, or be even completely reversed, by the operation of particular disturbing causes.

The larger Crustacea possess a circulatory apparatus still more extensive and complete, accompanied by a corresponding increase in the energy of the vital functions. As we follow this system in the more highly organized tribes of this class, we find the powers of the dorsal vessel becoming more and more concentrated in its anterior extremity; till, in the *Decapoda*, a family which comprehends the Lobster and the Crab, we find this part dilated into an oval or globular organ, with very muscular coats, capable of vigorous contractions, propelling its contents with considerable force into the vessels, and therefore clearly entitled to the appellation of *heart*. The distinction between arteries and veins, which can scarcely be made with any precision in the systems of the inferior tribes, is here perfectly determined by the existence of this central organ of propulsion: for the vessels into which the blood is sent by its contractions, and which, ramifying extensively, distribute it to distant parts, are indisputably *arteries;* and, conversely, the vessels which collect the blood from all these parts, and bring it back to the heart, are as decidedly *veins*. The heart of the lobster is situated immediately under the carapace, or shell of the dorsal region of the thorax, in a plane posterior to the stomach, where it is not liable to be pressed against the resisting shell, when the stomach is distended. Its pulsations are very distinct, and are performed with great regularity.

The importance of the heart, as the prime agent in the circulation, increases as we advance to the higher classes of animals, whose more active and energetic functions require a continual and rapid renewal of nutrient fluid, and render necessary the introduction of farther refinements into its structure. The supply of blood to the heart, being in a constant stream, produces a gradual dilatation of the cavity which receives it; and the muscular fibres of that cavity are not excited to contraction, until they are stretched beyond a certain point. But in order effectually to drive the blood into every part of the arterial system, where it has great resistances to overcome, a considerable impulsive force is required, implying a sudden as well as powerful muscular action. This object is attained, in all vertebrated animals, by providing a second muscular cavity, termed a *ventricle*, into which the first cavity, or *auricle*, throws the blood it has received from the veins, with a sudden impulse; and thus the ventricle, being rapidly distended, is excited to a much more quick and forcible contraction than the auricle, and propels the blood it contains into the artery, with an impetus incomparably greater than could have resulted from the action of the auricle alone. Fig. 350 represents the heart with its

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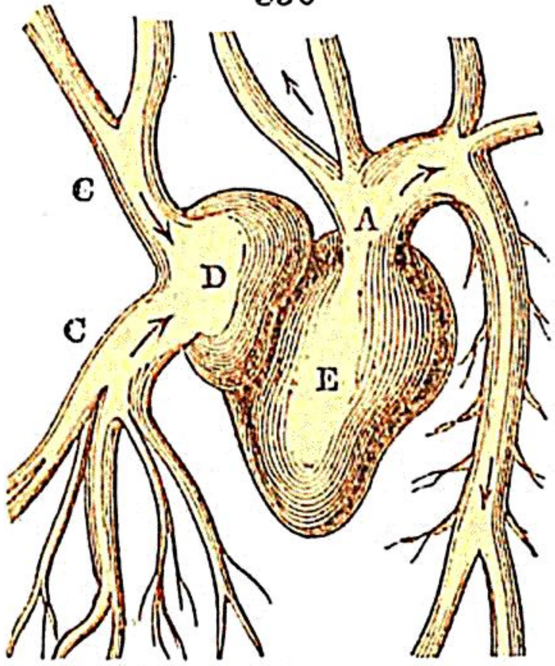

two cavities; D being the auricle, and E the ventricle; together with the main trunks of the veins (C, C,) which convey the blood into the auricle; and those of the arteries (A,) which receive it from the ventricle for distribution over the whole system.

The force of contraction in the principal cavity of the heart being thus increased, it becomes necessary to provide additional securities against the retrograde motion of its fluid contents. Valves are accordingly interposed between the auricle and ventricle; and great refinement of mechanism is displayed in their construction. Fig. 351 represents their

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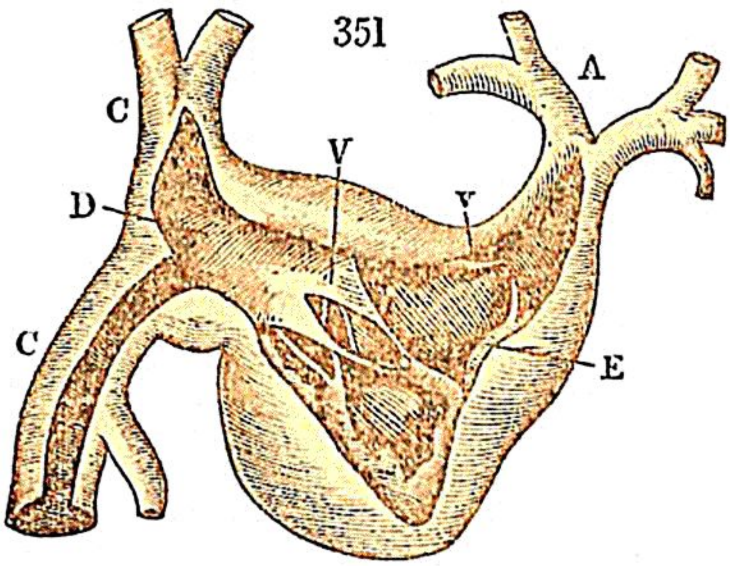

appearances (at v) when the cavities, both of the auricle (D,) and the ventricle (E) are laid open: c, c, as before, being the upper and lower venæ cavæ, and A, the main trunk of the aorta. These valves are composed of two loose membranes, the fixed edges of which are attached circularly to the aperture of communication between the cavities, and their loose edges project into the ventricle; so that they perform the office of flood-gates, allowing a free passage to the blood when it is impelled into the ventricle, and being pushed back the moment the ventricle contracts; in which latter case they concur in accurately closing the aperture, and preventing the return of a single drop into the auricle. These valves being attached to a wide circular aperture, it is necessary that they should be restrained from inverting themselves into the auricle, at each contraction of the ventricle. For this purpose there are provided slender ligaments (which are seen in Fig. 351,) fixed by one end to the edge of the valve, and by the other to some part of the inner surface of the ventricle, so that the valve is always kept within the cavity of the latter. In the auricle, the same purpose is answered by the oblique direction in which the veins enter it.

The arteries themselves, especially the main trunk of the aorta, as it issues from the heart, are muscular, and when suddenly distended, contract upon their contents. It was necessary, therefore to provide means for preventing any reflux of blood into the ventricle during their contractions; and for this purpose another set of valves (*v*, Fig. 351,) is placed at the beginning of these tubes, where they arise from the ventricle. These valves consist usually of three membranes, which have the form of a crescent, and are capable of closing the passage so accurately, that not a drop of blood can pass between them.*

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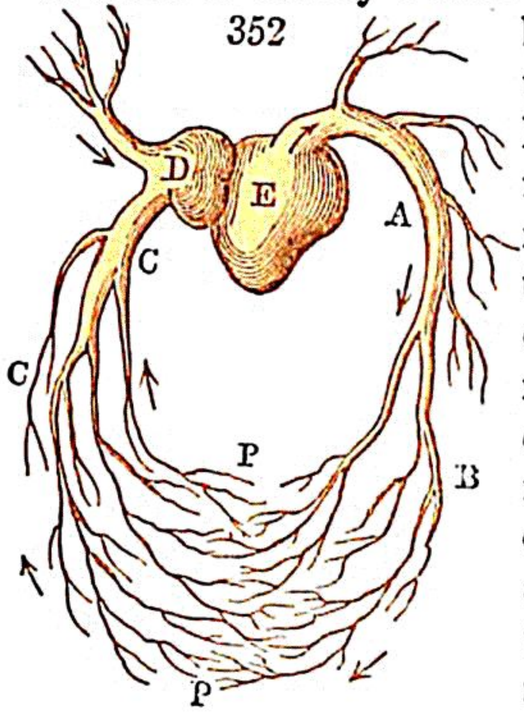

In order to convey a more clear idea of the course of the blood in the circulatory system, I have drawn the diagram, Fig. 352, exhibiting the general arrangement of its component parts. The main arterial trunk or Aorta (A,) while proceeding in its course, gives off numerous branches, (B,) which divide and subdivide, till the ramifications (P P) arrive at an extreme degree of minuteness; and they are finally distributed to every organ, and to the remotest extremities of the body. They frequently, during their course, communicate with one another, or *anastomose*, as it is termed, by collateral branches, so as to provide against interruptions to the circulation, which might arise from accidental obstructions in any particular branches of this extended system of canals. The minutest vessels (P P,) which, in incalculable numbers, per-

* In the artery of the shark, and other cartilaginous fishes, where the action of the vessel is very powerful, these valves are much more numerous, and arranged in rows, occupying several parts of the artery. Additional valves are also met with in other fishes at the branching of large arteries.

vade every part of the frame, are named, from their being finer than hairs, *capillary vessels*.

After the blood, thus transmitted to the different parts of the body by the arteries, has supplied them with the nourishment they require, it is conveyed back to the heart by the veins, which, commencing from the extreme ramifications of the arteries, bend back again in a course directed towards the heart. The smaller branches join in succession to form larger and larger trunks, till they are at length all united into one or two main pipes, called the *Venæ cavæ*, (c,) which pour their accumulated torrent of blood into the general reservoir, the heart; entering first into the auricle (D,) and thence being carried forward into the ventricle (E,) which again propels it through the Aorta. The veins are larger and more numerous than the arteries, and may be compared to rivers, which, collecting all the water that is not imbibed by the soil, and reconveying it into its general receptacle, the ocean, perform an analogous office in the economy of the earth.

The communications of the capillary arteries with the veins are beautifully seen, under the microscope, in the transparent membranes of frogs or fishes. The splendid spectacle, thus brought within the cognizance of our senses, of unceasing activity in the minutest filaments of the animal frame, and of the rapid transit of streams of fluid, bearing along with them minute particles, which appear to be pressing forwards, like the passengers in the streets of a crowded city, through multitudes of narrow and winding passages, can never fail, when first beheld, to fill the mind with astonishment;* a feeling which must be exalted to the highest admiration on reflecting that what we there behold is at all times going on

* Lewenhoek, speaking of the delight he experienced on viewing the circulation of the blood in tadpoles, uses the following expressions: "This pleasure has oftentimes been so recreating to me, that I do not believe that all the pleasures of fountains, or water-works, either natural or made by art, could have pleased my sight so well, as the view of these creatures has given me."—Phil. Trans. xxii. 453.

within us, during the whole period of our lives, in every, even the minutest, portion of our frame. How inadequate, then, must be any ideas we are capable of forming of the incalculable number of movements and of actions, which are conducted in the living system; and how infinite must be the prescience and the wisdom, by which these multifarious and complicated operations were so deeply planned and so harmoniously adjusted!

§ 3. *Respiratory Circulation.*

THE object of the circulation is not merely to distribute the blood through the general system of the body; it has, also, another and a very important office to perform. The blood undergoes, in the course of its circulation, considerable changes, both in its colour and its chemical composition. The healthy blood transmitted by the arteries is of a bright scarlet hue; that brought back by the veins is of a dark purple, from its containing an excess of carbon, and is consequently unfit to be again circulated. Whenever, from some derangement in the functions, this dark blood finds its way

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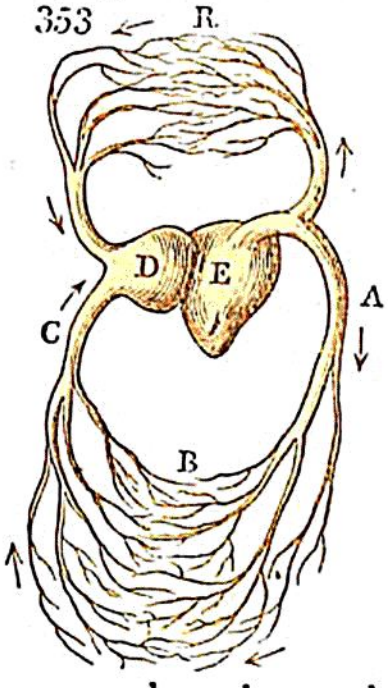

into the arteries, it acts as a poison on every organ which it reaches, and would soon, if it continued to circulate, destroy life. Hence, it is necessary that the blood which returns by the veins should undergo purification, by exposure either to the air itself, or to a fluid containing air, for the purpose of restoring and preserving its salutary qualities. The heart and vascular system have, therefore, the additional task assigned them of conveying the vitiated venous blood to certain organs, where it may have access to the air, and receive its vivyfying influence; and to this office a distinct set of arteries and veins is appropriated, constituting a distinct circulation. This I have endeavoured to illustrate by the diagram, Fig. 353 where D represents the auricle, and E the ventricle of the heart; and A and C, the main arterial and venous trunks; and where the two circulations are, for the sake of distinctness, supposed to be separated from one another, so that the two systems of vessels may occupy different parts of the diagram. The vessels which pervade the body generally (B,) and are subservient to nutrition, belong to what is termed the *greater*, or *systemic* circulation: those which circulate the blood through the respiratory organs, (R,) for the purpose of aeration, compose the system of the *lesser*, or *respiratory* circulation.

Few subjects in Physiology present a field of greater interest than the comparison of the modes in which these two great functions are, in all the various classes of animals, exactly adjusted to each other. So intimately are the organs of circulation related to those which distribute the blood to the respiratory organs, that we never can form a clear idea of the former, without a close reference to the latter of these systems. While describing the several plans of circulation presented to us by the different classes, I shall be obliged, therefore, to assume both the necessity of the function of respiration, and of a provision of certain organs for the reception of air, (either in its gaseous form, or as it is contained in water,) where the blood may be subjected to its action. It is necessary, also, to state that the organs for receiving atmospheric air, in its gaseous state, are either *lungs*, or *pulmonary cavities*, while those which are constructed for aquatic respiration are termed *gills*, or *branchiæ;* the arteries and the veins which carry on this respiratory circulation, being termed *pulmonary*, or *branchial*, according as they relate to the one or the other description of respiratory organs.

In many animals it is only a part of the circulating blood which undergoes aeration; the pulmonary or branchial arteries and veins being merely branches of the general system of blood vessels: so that in this case, which is represented in the preceding figure (353,) the lesser circulation is included as a part of the general circulation. But in all the higher classes the whole of the blood is, in some part of its circuit, subjected to the influence of the air; the pulmonary, being then distinct from the systemic circulation. In the Annelida, for instance, the venæ cavæ, which bring back the blood from the system, unite to form one or more vessels, which then assume the function of arteries, subdividing and ramifying upon the branchial organs; after this the blood is again collected by the branchial veins, which unite into one trunk to form the arteries of the systemic circulation.

Most insects, especially when arrived at the advanced stages of their development, have too imperfect a circulation to effect the thorough aeration of the blood: and indeed a greater part of that fluid is not contained within the vascular system, but permeates the cavities and cellular texture of the body. It will be seen, when I come to treat of respiration, that the same object is accomplished by means totally independent of the circulatory apparatus; namely, by a system of air-tubes, distributed over every part of the body. But an apparatus of this kind is not required in those Arachnida, where the circulation is vigorous, and continues during the whole of life: here, then, we again meet with a pulmonary as well as a systemic circulation, in conjunction with internal cavities for the reception of air.

In the Crustacea the circulation is conducted on the same general plan as in the Annelida; the blood from every part of the body being collected by the Venæ Cavæ, which are exceedingly capacious, and extend, on each side, along the lower surface of the abdomen. They send out branches, which distribute the blood to the gills; but these branches, at their origin, suddenly dilate, so as to

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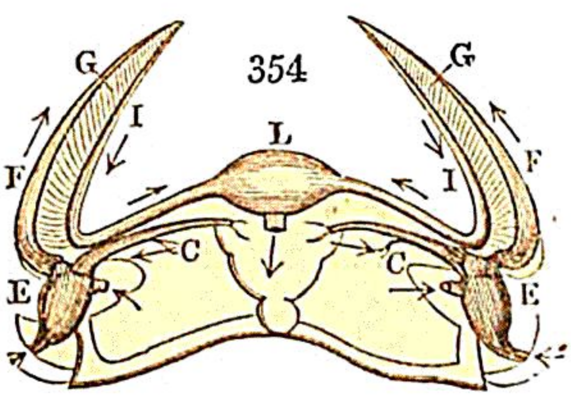

form large receptacles, which are called *sinuses*, where the blood is allowed to accumulate, and where, by the muscularity of the expanded coats of the vessels, it receives an additional force of propulsion. From the branchiæ the blood is returned by another set of veins to the elongated heart formerly described, and propelled by that organ into the systemic arteries. Fig. 354 shows the relative situation of these vessels, when isolated and viewed from behind in the *Maia squinado.* C, C, are the venæ cavæ; E, E, the venous sinuses above mentioned; F, F, are the branchial arteries; G, the gills, or branchiæ; and I, I, the branchial veins terminating in the heart L.*

In the Mollusca, the heart acquires greater size, compared with the other organs, and exerts a proportionally greater influence as the prime mover in the circulation. A beautiful gradation may be perceived in the development of this organ in the several orders of this class; the *Branchiopoda* having two hearts, one placed upon each of the two lateral trunks of the branchial veins; the *Gasteropoda* having a single heart, furnished with an auricle; and the *Acephala* being provided with a heart, which has a single ventricle, but two auricles, corresponding to the two trunks of the branchial veins.†

The most remarkable variety of structure is that exhibited by the Cephalopoda. We have already seen, in the Crustacea, dilatations of the venæ cavæ, at the origin of the branchial arteries; but in the *Nautilus* the dilatations of the branchial veins are of such a size, as to be almost entitled to the appellation of auricles. The *Sepia*, in whose highly organized system there is required great additional power to propel the blood with sufficient force through the gills, is provided with a large and complicated branchial apparatus; and

* A minute account of the organs of circulation in the crustacea is given by Audouin and Milne Edwards, in the Annales des Sciences Naturelles, xi. 283 and 352, from which work the above figure is taken.

† A great number of bivalve Mollusca exhibit the singular peculiarity of the lower portion of the intestinal tube traversing through the cavity of the heart.

the requisite power is supplied by two additional hearts, situated on the venæ cavæ, of which they appear as if they were dilatations, immediately before the branchial arteries are sent off.* They are shown at E, E, Fig. 355, which re-

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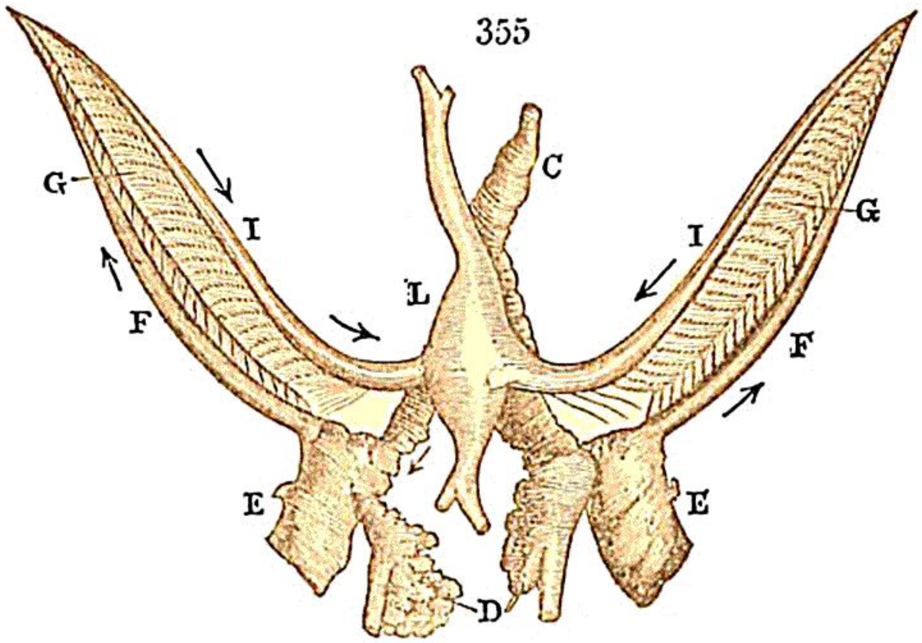

presents this part of the vascular system of the *Loligo*, detached from the surrounding parts; the course of the blood being indicated by arrows. C is one of the three trunks constituting the venæ cavæ, proceeding from above, dividing into two branches as it descends, and terminating, conjointly with the two venous trunks (D,) which are coming from below, into the lateral or branchial hearts (E, E,) already mentioned. Thence the blood is conveyed by the branchial arteries, (F, F,) on each side, to the gills (G,) and returned, by the branchial veins (I,) to the large central, or systemic heart (L,) which again distributes it, by means of the systemic arteries, to every part of the body. The cuttle-fish tribe is the only one thus furnished with three distinct hearts for carrying on a double circulation: none of these hearts are furnished with auricles.

The remarkable distribution of the muscular powers which give an impulse to the circulating fluids, met with in the Sepia, constitutes a step in the transition from Mollusca

* These veins are surrounded by a great number of blind pouches, which have the appearance of a fringe; the use of this singular structure is unknown.

to Fishes. In this latter class of animals, the two lateral hearts have united into a single central heart, while the aortic heart has entirely disappeared; and thus the position of the heart with respect to the two circulations is just the reverse of that which it has in the invertebrated classes.

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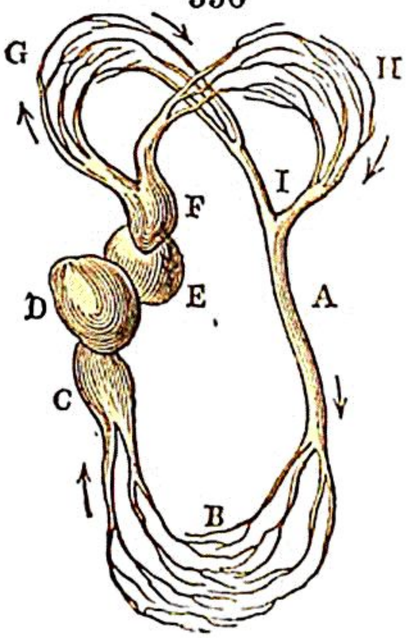

The plan in Fishes is shown in the diagram, Fig. 356, where the central organs are seen to consist of four cavities, C, D, E, F, opening successively the one into the other. The heart belongs exclusively to the gills; and there proceeds from it, not the aorta, but the trunk of those branchial arteries (F,) which convey the whole of the blood to the respiratory organs (G, H.) This blood, after being there aerated, is collected by the branchial veins (I,) which unite into a single trunk (A,) passing down the back, and performing, without any intermediate heart, the office of an aorta; that is, it divides into innumerable branches, and distributes the blood to every part of the system.* The blood is then reconveyed to the heart by the ordinary veins, which form a large vena cava (C.) This vein is generally considerably dilated at its termination, or just before it opens into the auricle, constituting what has been termed a *venous sinus* (S.) This, then is followed by the auricle (D) and the ventricle (E;) but, besides these cavities, there is also a fourth (F,) formed by a dilatation of the beginning of the branchial artery, and termed the *bulbus arteriosus*, contributing, doubtless, to augment the impetus with which the blood is sent into the branchial arteries.

* The caudal branch of the aorta is protected by the roots of the inferior spinous processes, joining to form arches through which it passes; and frequently the artery is contained in a bony channel, formed by the bodies of the vertebræ, which effectually secures it from all external pressure. In the sturgeon even the abdominal aorta is thus protected, being entirely concealed within this bony canal.

The circulation in Reptiles is not double, like that of fishes; for only a part of the blood is brought under the influence of the air in the pulmonary organs. All the animals belonging to this class are cold-blooded, sluggish, and inert; they subsist upon a scanty allowance of food, and are astonishingly tenacious of life. The simplest form in which we meet with this mode of circulation is in the Batrachia; it is shown in the diagram, Fig. 357. The heart of the Frog, for example, may be considered as consisting of a single auricle (D,) and a single ventricle (E.*) From the latter there proceeds one great arterial trunk, which is properly the aorta. This aorta soon divides into two trunks, which, after sending branches to the head and neck, bend downwards (as it is seen at O, P,) and unite to form a single trunk (A,) which is the descending aorta. From this vessel proceed all the arteries which are distributed to the trunk and to the limbs, and which are represented as situated at B: these arterial ramifications are continued into the great venous trunks, which, as usual, constitute the venæ cavæ (C,) and terminate in the auricle (D.)

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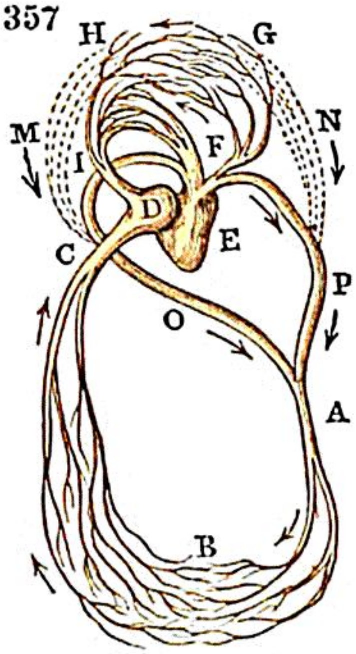

From each of the trunks which arise from the primary division of the aorta, there proceed the small arteries (F,) which are distributed to the lungs (G, H,) and convey to those

* Dr. Davy has observed that although the auricle appears single, when viewed externally, its cavity is in reallity divided into two compartments by a transparent membranous partition, in which some muscular fibres are apparent: these communicate with the cavity of the ventricle by a common opening, provided with three semilunar valves. Edin. Phil. Journal; xix. 161.

Mr. Owen informs me that his own observations confirm those of Dr. Davy; and that he has discovered that the *Siren* has also a distinct pulmonic auricle; whence he infers that wherever lungs are sufficiently developed to effect a change in the blood, that fluid is conveyed to the ventricle by a distinct route, and the pulmonary veins thus defended from the pressure of the blood accumulated in the right auricle.

organs a part only of the mass of circulating blood. To these pulmonary arteries there correspond a set of veins, uniting in the trunks (I,) which bring back the aerated blood to the auricle of the heart (D,) where it is mixed with the blood which has returned by the venæ cavæ (C,) from the general circulation. Thus the blood is only partially aerated, in consequence of the lesser circulation being here only a branch of the greater.

Nothing is more curious or beautiful than the mode in which Nature conducts the gradual transition of the branchial circulation of the tadpole, into the pulmonary circulation of the frog. In the former, the respiratory organs are constructed on the model of those of fishes, and respiration is performed in the same manner as in that class of animals; the heart is consequently essentially branchial, sending the whole of its blood to the gills, the veins returning from which (describing the course marked by the dotted lines M, N, in the diagram,) unite, as in fishes, to form the descending aorta. As the lungs develope, small arterial branches, arising from the aorta, are distributed to those organs, and in proportion as these arteries enlarge, the branchial arteries diminish; until, on there becoming entirely obliterated, the course of the blood is wholly diverted from them, and flows through the enlarged lateral trunks (O, P,) of which the junction constitutes the descending aorta. This latter vessel now receives the whole of its blood directly from the heart; which, from being originally a branchial, has become a systemic heart.

The heart of the Chelonian reptiles, such as the ordinary species of Tortoises and Turtles, has two distinct auricles; the one, receiving the blood from the pulmonary veins; the other, from those of the body generally; so that the mixture of aerated and vitiated blood takes place, not in the auricle, but in the ventricle itself. When all the cavities are distended with blood, the two auricles being nearly of the same size as the ventricle, the whole has the appearance of a union of three hearts. The circulatory system of the Ophidia is constructed on a plan very similar to that of the Chelonia.

In the Saurian reptiles, the structure becomes again more complicated. In the Chameleon each auricle of the heart has a large venous sinus, appearing like two supplementary auricles.* The heart of the Crocodile has not only two auricles, but its ventricle is divided by two partitions, into three chambers: each of the partitions is perforated to allow of a free communication between the chambers; and the passages are so adjusted as to détermine the current of aerated blood, returning from the lungs, into those arteries, more especially, which supply the head and the muscles of the limbs; while the vitiated blood is made again to circulate through the arteries of the viscera.†

It is in warm-blooded animals that the two offices of the circulation are most efficiently performed; for the whole of the blood passes, alternately, through the greater and the lesser circulations, and a complete apparatus is provided for each. There are, in fact, two hearts, the one on the left side impelling the blood through the greater or systemic circulation; the other, on the right side, appropriated to the lesser, or pulmonary circulation. The annexed diagram, (Fig. 359,)

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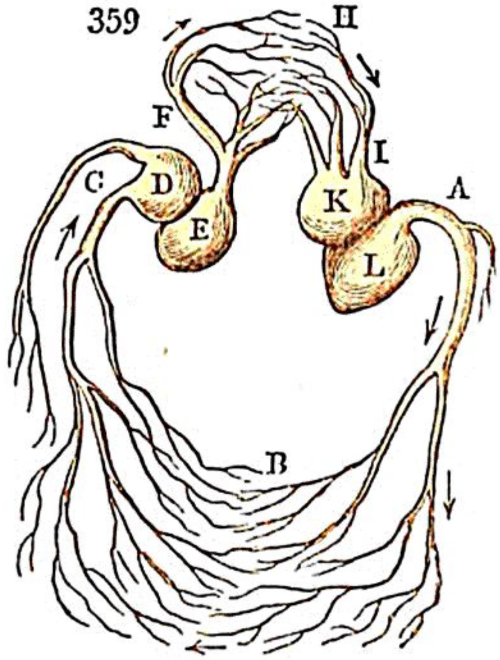


illustrates the plan of the circulation in warm-blooded animals. From the left ventricle (L.) the blood is propelled into the aorta (A,) to be diffused through the arteries of the system (B) to every part, and penetrating into all the capillary vessels; thence it is returned by the veins, through the venæ cavæ (C,) to the right auricle (D,) which delivers it into the right ventricle (E.) This right ventricle impels the blood, thus received, through the pulmonary arteries

* Houston; Trans. Roy. Irish Acad. xv. 189.

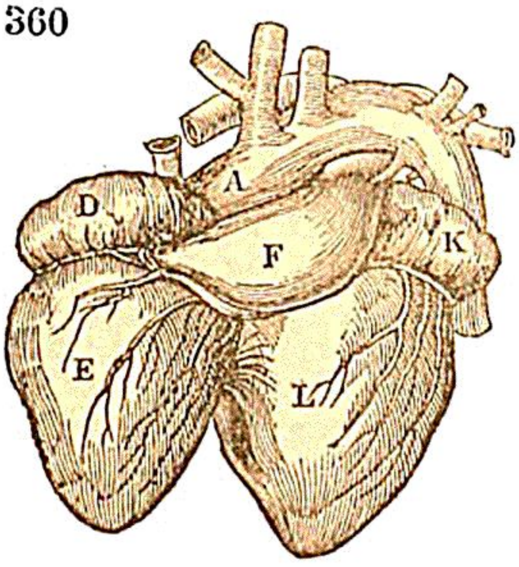
† It would appear, from this arrangement of the vessels, that the brain, or

(F,) into the lungs (at H,) where it is aerated, and whence it is reconveyed by the pulmonary veins (I,) into the left auricle (K,) which immediately pours it into the left ventricle (L,) the point from whence we set out.

Both the right and the left heart have their respective auricles and ventricles; but they are all united in one envelope, so as to compose, in appearance, but a single organ:* still, however, the right and left cavities are kept perfectly distinct from one another, and are separated by thick partitions, allowing of no direct transmission of fluid from the one side to the other. These two hearts may, therefore, be compared to two sets of chambers under the same roof, having each their respective entrances and exits, with a party-wall of separation between them. This junction of the two hearts

central organ of the nervous system, requires, more than any other part, a supply of oxygenated blood for the due performance of its functions. The curious provision which is made for sending this partial supply of blood, of a particular quality, in the larger kinds of reptiles, such as the *Crocodile*, has been pointed out by many anatomists; but has been lately investigated more particularly by M. Martin St. Ange. (See the Report of G. St. Hilaire, Revue Médicale, for April, 1833.) It is found that in these animals, as well as in the Chelonia, a partial respiratory system is provided for by the admission, through two canals opening externally, of aerated water into the cavity of the abdomen, where it may act upon the blood which is circulating in the vessels. Traces of canals, of this description, are also met with in some of the higher classes of vertebrated animals, as, for instance, among the Mammalia, in the *Monotremata* and the *Marsupialia*.

360



* A remarkable exception to this general law of consolidation occurs in the heart of the *Dugong*, represented in Fig. 360, in which it may be seen that the two ventricles, E and L, are almost entirely detached from each other. In this figure, which is taken from the Philosophical Transactions for 1820, D is the right or systemic auricle, E the right or pulmonary ventricle, F the pulmonary artery, K the left or pulmonary auricle, L the left or systemic ventricle, and A the aorta.

is conducive to their mutual strength; for the fibres of each intermix and even co-operate in their actions, and both circulations are carried on at the same time; that is, both ventricles contract or close at the same instant; and the same applies to the auricles. The blood which has just returned from the body, and that from the lungs, the former by the venæ cavæ, the latter by the pulmonary veins, fill their respective auricles at the same instant; and both auricles, contracting at the same moment, discharge their contents simultaneously into their respective ventricles. In the like manner, at the moment when the left ventricle is propelling its aerated blood into the aorta, for the purposes of general nutrition, the right ventricle is likewise driving the vitiated blood into the pulmonary artery, in order that it may be purified by the influence of the air. Thus, the same blood which, during the interval of one pulsation, was circulating through the lungs, is, in the next, circulating through the body; and thus do the contractions of the veins, auricles, ventricles, and arteries, all concur in the same general end, and establish the most beautiful and perfect harmony of action.*

§ 4. *Distribution of Blood Vessels.*

In the distribution of the arteries in the animal system, we meet with numberless proofs of wise and provident arrangement. The great trunks of both arteries and veins, which carry on the circulation in the limbs, are conducted always on the interior sides, and along the interior angles

* Evidence is afforded of the human conformatian being expressly adapted to the erect position of the body by the position of the heart, as compared with quadrupeds; for, in the latter, the heart is placed directly in the middle of the chest, with the point towards the abdomen, and not occupying any portion of the diaphragm; but, in man, the heart lies obliquely on the diaphragm, with the apex turned towards the left side.

of the joints, and generally seek the protection of the adjacent bones. Grooves are formed in many of the bones, where arteries are lodged, with the evident intention of affording them a more secure passage. Thus, the principal arteries which supply the muscles of the chest, proceed along the lower edges of the ribs, in deep furrows formed for their protection. Arteries are often still more effectually guarded against injury or obstruction by passing through complete tubes of solid bone. An instance occurs in the arteries supplying the teeth, which pass along a channel in the lower jaw, excavated through the whole length of the bone. The aorta in fishes, after having supplied arteries to the viscera of the abdomen, is continued to the tail, and passes through a channel, formed by bony processes from the vertebræ; and the same kind of protection is afforded to the corresponding artery in the Cetacea. In the fore leg of the Lion, which is employed in actions of prodigious strength, the artery, without some especial provision, would have been in danger of being compressed by the violent contractions of the muscles; to guard against this inconvenience, it is made to pass through a perforation in the bone itself, where it is completely secure from pressure.*

The energy of every function is regulated in a great measure by the quantity of blood which the organs exercising that function receive. The muscles employed in the most vigorous actions are always found to receive the largest share of blood. It is commonly observed that the right fore leg of quadrupeds, as well as this right arm in man, is stronger than the left. Much of the superior strength is, no doubt, the result of education; the right arm being habitually more used than the left. But still the different mode in which the arteries are distributed to the two arms constitutes a natural source of inequality. The artery supplying the right arm with blood is the first which arises from the

* In like manner the coffin bone of the Horse is perforated for the safe conveyance of the arteries going to the foot.

aorta, and it proceeds in a more direct course from the heart than the artery of the left arm, which has its origin in common with the artery of that side of the head. Hence it has been inferred that the right arm is orginally better supplied with nourishment than the left. It may be alleged, in confirmation of this view, that in birds, where any inequality in the actions of the two wings would have disturbed the regularity of flight, the aorta, when it has arrived at the centre of the chest, divides with perfect equality into two branches, so that both wings receive precisely the same quantity of blood; and the muscles, being thus equally nourished, preserve that equality of strength, which their function rigidly demands.

When a large quantity of blood is wanted in any particular organ, and yet the force with which it would arrive, if sent immediately by large arteries, might injure the texture of that organ, contrivances are adopted for diminishing its impetus, either by making the arteries pursue very winding and circuitous paths, or by subdividing them, before they reach their destination, into a great number of smaller arteries. The delicate texture of the brain, for instance, would be greatly injured by the blood being impelled with any considerable force against the sides of the vessels which are distributed to it; and yet a very large supply of blood is required by that organ for the due performance of its functions. Accordingly we find that all the arteries which go to the brain are very tortuous in their course; every flexure tending considerably to diminish the force of the current of blood.

In animals that graze, and keep their heads for a long time in a dependent position, the danger from an excessive impetus in the blood flowing towards the head is much greater than in other animals; and we find that an extraordinary provision is made to obviate this danger. The arteries which supply the brain, on their entrance into the basis of the skull, suddenly divide into a great number of minute branches, forming a complicated net-work of vessels, an arrangement which, on the well known principles of hydraulics, must greatly check the velocity of the blood conducted through them. That such is the real purpose of this structure is evident from the branches afterwards uniting into larger trunks when they have entered the brain, through the substance of which they are then distributed exactly as in other animals, where no such previous subdivision takes place.

In the *Bradypus tridactylus*, or great American Sloth, an animal remarkable for the slowness of its movements, a plan somewhat analogous to the former is adopted in the structure of the arteries of the limbs. These arteries, at their entrance into both the upper and lower extremities, suddenly divide into a great number of cylindric vessels of equal size, communicating in various places by collateral branches. These curiously subdivided arteries are exclusively distributed to the muscles of the limbs; for all the other arteries of the body branch off in the usual manner. This structure, which was discovered by Sir A. Carlisle,* is not confined to the Sloth, but is met with in other animals, as the *Lemur tardigradus*, and the *Lemur loris*, which resemble the sloth in the extreme sluggishness of their movements. It is extremely probable, therefore, that this peculiarity in the muscular power results from this remarkable structure in the arteries; or is at least in some way connected with it. In the Lion, and some other beasts of prey, a similar construction is adopted in the arteries of the head, probably with a view to confer a power of more permanent contraction in the muscles of the jaws for holding a strong animal, such as a buffalo, and carrying it to a distance.

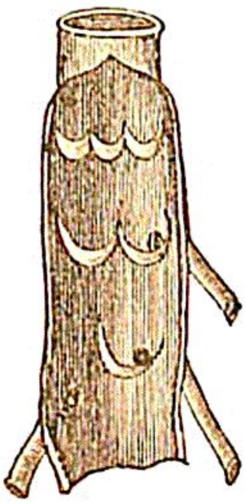
That we may form an adequate conception of the immense power of the ventricle, or prime mover in the circulation of the blood, we have but to reflect on the numerous obstacles impeding its passage through the arterial system. There is, first, the natural elasticity of the coats of the ar-

* Phil. Trans. for 1800, p. 98, and for 1804, p. 17.

teries, which must be overcome before any blood can enter them. Secondly, the arteries are, in most places, so connected with many heavy parts of the body, that their dilatation cannot be effected without, at the same time, communicating motion to them. Thus, when we sit cross-legged, the pulsation of the artery in the ham, which is pressed upon the knee of the other leg, is sufficiently strong to raise the whole leg and foot at each beat of the pulse. If we consider the great weight of the leg, and reflect upon the length of the lever by which that weight acts, we shall be convinced of the prodigious force which is actually exerted by the current of blood in the artery in thus raising the whole limb. Thirdly, the winding course, which the blood is forced to take, in following all the oblique and serpentine flexures of the arteries, must greatly impede its motion. But notwithstanding these numerous and powerful impediments, the force of the heart is so great, that, in defiance of all obstacles or causes of retardation, it drives the blood with immense velocity into the aorta. The ventricle of the human heart does not contain more than an ounce of blood, and it contracts at least seventy times in a minute; so that above three hundred pounds of blood are passing through this organ during every hour that we live. "Consider," says Paley, "what an affair this is when we come to very large animals. The aorta of a whale is larger in the bore than the main pipe of the water-works at London Bridge; and the water roaring in its passage through that pipe is inferior in impetus and velocity to the blood gushing through the whale's heart. An anatomist who understood the structure of the heart, might say before hand that it would play; but he would expect, from the complexity of its mechanism, and the delicacy of many of its parts, that it should always be liable to derangement, or that it would soon work itself out. Yet shall this wonderful machine go on night and day, for eighty years together, at the rate of a hundred thousand strokes every twenty-four hours, having at every stroke a great resistance to overcome, and shall continue this action for this length of time, without disorder and without weariness. To those who venture their lives in a ship, it has often been said that there is only a plank between them and destruction; but in the body, and especially in the arterial system, there is in many parts only a membrane, a skin, a thread." Yet how well has every part been guarded from injury: how providentially have accidents been anticipated: how skilfully has danger been averted!

The impulse which the heart, by its powerful contraction, gives to the blood, is nearly expended by the time it has reached the veins: nature has accordingly furnished them with numerous valves, all opening in a direction towards the heart; so that as long as the blood proceeds in its natural course, it meets with no impediment; while a retrograde motion is effectually prevented.

365



Hence external pressure, occasionally applied to the veins, assist in promoting the flow of blood towards the heart; and hence the effects of exercise in accelerating the circulation. Valves are more especially provided in the veins which pass over the muscles of the extremities, or which run immediately beneath the skin; while they are not found in the more internal veins belonging to the viscera, which are less exposed to unequal pressure. These valves are delineated in Fig. 365, which represents the interior of one of the large veins.

The situation and structure of the valves belonging to the hydraulic apparatus of the circulation furnish as unequivocal proofs of design as any that can be adduced. It was the observation of these valves that first suggested to the mind of Harvey the train of reflections which led him to the discovery of the real course of the blood in the veins, the arteries, and the heart. This great discovery was one of the earliest fruits of the active and rational spirit of inquiry, which, at the era of Bacon's writings, was beginning to awaken the human mind from its long night of slumber, and to dissipate the darkness which had, for so many ages, overshadowed the regions of philosophy and science. We cannot but feel a pride, as Englishmen, in the recollection, that a discovery of such vast importance as that of the circulation of the blood, which has led to nearly all the modern improvements in the medical art, was made by our own countryman, whose name will for ever live in the annals of our race, as one of its most distinguished benefactors. The consideration, also, that it had its source in the study of comparative anatomy and physiology, affords us a convincing proof of the great advantages that may result from the cultivation of these sciences; to which Nature, indeed, seems, in this instance, expressly to have invited us, by displaying to our view, in the organs of the circulation, an endless diversity of combinations, as if she had purposely designed to elucidate their relations with the vital powers, and to assist our investigations of the laws of organized beings.

CHAPTER XI.

Respiration.

§ 1. *Respiration in General.*

The action of atmospheric air is equally necessary for the maintenance of animal and of vegetable life. As the ascending sap of plants cannot be perfected unless exposed to the chemical agency of air in the leaves, in like manner the blood of animals requires the perpetual renovation of its vital properties by the purifying influence of respiration. The great importance of this function is evinced by the constant provision which has been made by Nature, in every class of animals, for bringing each portion of their nutritive juices, in its turn, into contact with air. Even the circulation of these juices is an object of inferior importance, compared with their aeration; for we find that insects, which have but an imperfect and partial circulation of their blood, still require the free introduction of air into every part of their system. The necessity for air is more urgent than the demand for food; many animals being capable of subsisting for a considerable time without nourishment, but all speedily perishing when deprived of air. The influence of this element is requisite as well for the production and development, as for the continuance of organized beings in a living state. No vegetable seed will germinate, nor will any egg, even of the smallest insect, give birth to a larva, if kept in a perfect vacuum. Experiments on this subject have been varied and multiplied without end by Spallanzani, who found that insects under an air pump, confined in rarefied air, in general lived for shorter periods in proportion to the degree to which the exhaustion of air had been carried. Those species of infusoria, which are most tenacious of life, lived in very rarefied air for above a month: others perished in fourteen, eleven, or eight days; and some in two days only. In this imperfect vacuum, they were seen still to continue their accustomed evolutions, wheeling in circles, darting to the surface, or diving to the bottom of the fluid, and producing vortices by the rapid vibration of their cilia, to catch the floating particles which serve as their food: in course of time, however, they invariably gave indications of uneasiness; their movements became languid, a general relaxation ensued, and they at length expired. But when the vacuum was rendered perfect, none of the infusions of animal or vegetable substances, which, under ordinary circumstances, soon swarm with millions of these microscopic beings, ever exhibited a single animalcule; although they soon made their appearance in great numbers, if the smallest quantity of air was admitted into the receiver.

Animals which inhabit the waters, and remain constantly under its surface, such as fishes, and the greater number of mollusca, are necessarily precluded from receiving the direct action of atmospheric air in its gaseous state. But as all water exposed to the air soon absorbs it in large quantities, it becomes the medium by which that agent is applied to the respiratory organs of aquatic animals; and the oxygen it contains may thus act upon the blood with considerable effect; though not, perhaps, to the same extent as when directly applied in a gaseous state. The air which is present in water is, accordingly, as necessary to these animals as the air of the atmosphere is to those which live on land: hence, in our inquiries into the respiration of aquatic animals, it will be sufficient to trace the means by which the surrounding water is allowed to have access to the organs appropriated to this function; and in speaking of the action of the water upon them, it will always be understood that I refer to the action of the atmospheric air which that water contains.

Respiration, in its different modes, may be distinguished, according to the nature of the medium which is breathed, into *aquatic* or *atmospheric;* and in the former case, it is either *cutaneous*, or *branchial*, according as the respiratory organs are external or internal. Atmospheric respiration, again, is either *tracheal*, or *pulmonary*, according as the air is received by a system of the air tubes, denominated *tracheæ*, or into pulmonary cavities, composing the *lungs*.

§ 2. *Aquatic Respiration.*

Zoophytes appear in general to be unprovided with any distinct channels for conveying aerated water into the interior of their bodies, so that it may act in succession on the nutritive juices, and after performing this office, may be expelled, and exchanged for a fresh supply. It has accordingly been conjectured, on the presumption that this function is equally necessary to them as it is to all other animals, that the vivifying influence of the surrounding element is exerted through the medium of the surface of the body. Thus, it is very possible that in *Polypi*, while the interior surface of the sac digests the food, its external surface may perform the office of respiration; and no other mode of accomplishing this function has been distinctly traced in the *Acalephæ*. Medusæ, indeed, appear to have a farther object than mere progression in the alternate expansions and contractions of the floating edges of their hemispherical bodies; for these movements are performed with great regularity under all circumstances of rest or motion; and they continue even when the animal is taken out of the water and laid on the ground, as long as it retains its vitality. The specific name of the *Medusa pulmo** (the *Pulmone Marino* of the Italians,) is derived from the supposed resemblance of these movements to those of the lungs of breathing animals. The large cavities adjacent to the stomach, and which have been already pointed

* See the delineation of this animal in Fig. 135, vol. i. p. 198.

out in Fig. 249 and 252,* have been conjectured to be respiratory organs, chiefly, I believe, because they are not known to serve any other purpose.

The *Entozoa*, in like manner, present no appearance of internal respiratory organs; so that they probably receive the influence of oxygen only through the medium of the juices of the animals on which they subsist. *Planariæ*, which have a more independent existence, though endowed with a system of circulating vessels, have no internal respiratory organs; and whatever respiration they perform must be wholly cutaneous. Such is also the condition of several of the simpler kinds of *Annelida;* but in those which are more highly organized, an apparatus is provided for respiration, which is wholly external to the body, and appears as an appendage to it, consisting generally of tufts of projecting fibres, branching like a plume of feathers, and floating in the surrounding fluid. The *Lumbricus marinus*, or lob-worm,† for example, has two rows of branchial organs of this description, one on each side of the body; each row being composed of from fourteen to sixteen tufts. In the more stationary Annelida, which inhabit calcareous tubes, as the *Serpula* and the *Terebella*, these arborescent tufts are protected by a sheath which envelops their roots; and they are placed on the head, as being the only part which comes in contact with the water.

Most of the smaller *Crustacea* have branchiæ in the form of feathery tufts, attached to the paddles near the tail, and kept in incessant vibratory motion, which gives an appearance of great liveliness to the animal, and is more especially striking in the microscopic species. The variety of shapes which these organs assume in different tribes is too great to allow of any specific description of them in this place: but amidst these varieties, it is sufficiently apparent that their

* Pages 67 and 68 of this volume.

† Arenicola piscatorum. (Lam.) See a delineation of this marine worm in Fig. 135, vol. i. p. 198.

construction has been, in all cases, designed to obtain a considerable extent of surface over which the minute subdivisions of the blood vessels might be spread, in order to expose them fully to the action of aerated water.

The Mollusca, also, present great diversity in the forms of their respiratory organs, although they are all, with but a few exceptions, adapted to aquatic respiration. In many of the tribes which have no shell, as the *Thetis*, the *Doris*, and the *Tritonia*, there are arborescent gills projecting from different parts of the body, and floating in the water. In the *Lepas*, or barnacle, a curious family, constituting a connecting link between molluscous and articulated animals, these organs are attached to the bases of the *cirrhi*, or jointed tentacula, which are kept in constant motion, in order to obtain the full action of the water on the blood vessels they contain.

We are next to consider the extensive series of aquatic animals in which respiration is carried on by organs situated in the interior of the body. The first example of internal aquatic respiration occurs in the *Holothuria*, where there is an organ composed of ramified tubes, situated in a cavity having an external opening for the admission of the aerated water, which is brought to act on a vascular net-work, containing the nutritive juices of the animal, and apparently performing a partial circulation of those juices. A still more complicated system of respiratory channels occurs, both in the *Echinus* and *Asterias*, where they open by separate, but very minute orifices, distinct from the larger apertures through which the feet protrude; and the water admitted through these tubes is allowed to permeate the general cavity of the body, and is thus brought into contact with all the organs.

The animals composing the family of *Ascidiæ* have a large respiratory cavity, receiving the water from without, and having its sides lined with a membrane, which is thrown into a great number of folds; thus considerably extending the surface on which the water is designed to act. The entrance into the œsophagus, or true mouth, is situated at the bottom of this cavity; that is, at the part most remote from the external orifice; so that all the food has to pass through the respiratory cavity, before it can be swallowed, and received into the stomach.

In several of the *Annelida*, also, we find internal organs of respiration. The *Lumbricus terrestris*, or common earthworm, has a single row of apertures, about 120 in number, placed along the back, and opening between the segments of the body: they each lead into a respiratory vesicle, situated between the integument and the intestine.* The *Leech* has sixteen minute orifices of this kind on each side of the body, opening internally into the same number of oval cells, which are respiratory cavities; the water passing both in and out by the same orifices.†

The *Aphrodita aculeata* has thirty-two orifices on each side, placed in rows, opening into the abdominal cavity, and admitting the water, which is afterwards received into numerous pouches, containing cæcal processes of the intestine; so that the nutriment is aerated almost as soon as it is prepared by the digestive organs.‡

In all the higher classes of aquatic animals, where the circulation is carried on by means of a muscular heart, and where the whole of the blood is subjected, during its circuit, to the action of the aerated water, the immediate organs of respiration consist of long, narrow filaments, in the form of a fringe, and the blood vessels belonging to the respiratory system are extensively distributed over the whole surface of these filaments. Organs of this description are denominated

* A minute description of these organs is given by Morren, in pages 53 and 148 of his work, already quoted.

† The blood, after being aerated in these cells, is conveyed into the large lateral vessels, by means of canals, which pass transversely, forming loops, situated between the cæca of the stomach. These loops are studded with an immense number of small rounded bodies of a glandular appearance, resembling those which are appended to the venæ cavæ of the cephalopoda.

‡ Home, Philos. Trans. for 1815, p. 259.

Branchiæ or *Gills;* and the arteries which bring the blood to them are called the *branchial arteries;* the veins, which convey it back, being, of course, the *branchial veins.*

The larger *Crustacea* have their branchiæ situated on the under side of the body, not only in order to obtain protection from the carapace, which is folded over them, but also for the sake of being attached to the haunches of the feet-jaws, and thoracic feet, and thus participating in the movements of those organs. They may be seen in the *Lobster*, or in the *Crab*, by raising the lower edge of the carapace. The form of each branchial lamina is shown at *c*, in Fig. 354:* they consist of assemblages of many thousands of minute filaments, proceeding from their respective stems, like the fibres of a feather; and each group having a triangular, or a pyramidal figure. The number of these pyramidal bodies varies in the different genera; thus, the lobster has twenty-two, disposed in rows on each side of the body; but in the Crab, there are only seven on each side. To these organs are attached short and flat paddles, which are moved by appropriate muscles, and are kept in incessant motion, producing strong currents of water, evidently for the purpose of obtaining the full action of that element on every portion of the surface of the branchiæ.

In the greater number of Mollusca, these important organs, although external with respect to the viscera, are within the shell, and are generally situated near its outer margin. They are composed of parallel filaments, arranged like the teeth of a fine comb; and an opening exists in the mouth for admitting the water which is to act upon them.† In the

* Page 193, of this volume.

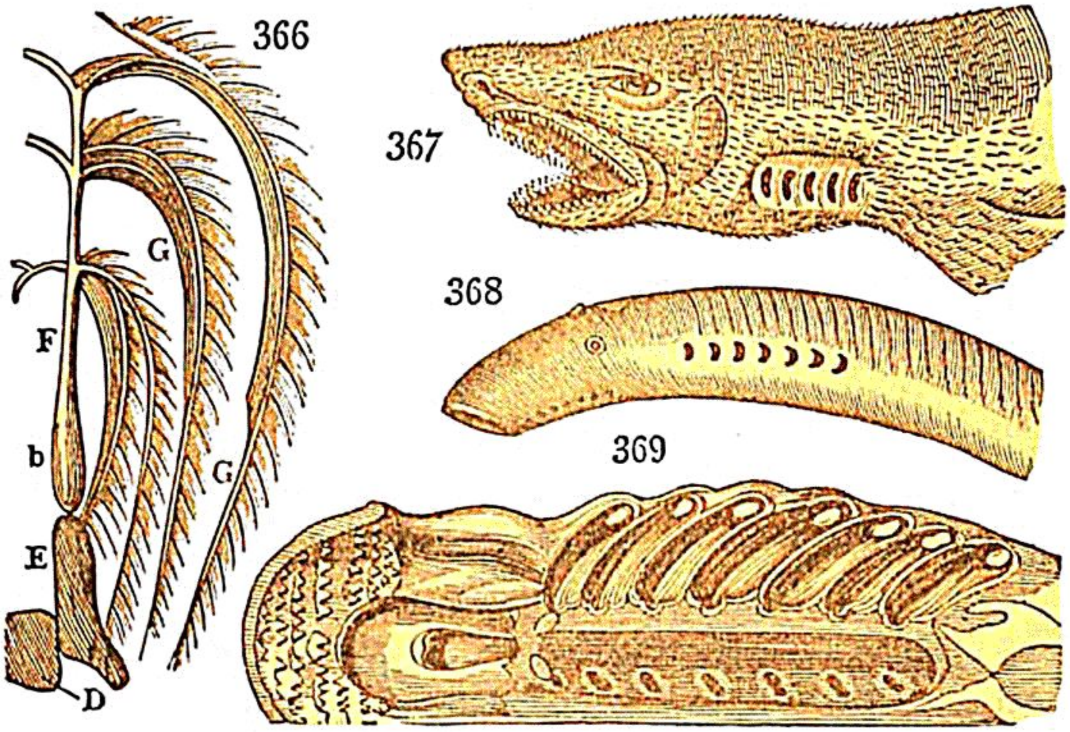
† These filaments appear, in many instances, to have the power of producing currents of water in their vicinity by the action of minute cilia, similar to those belonging to the tentacula of many polypi, where the same phenomenon is observable. Thus, if one of the branchial filaments of the fresh water muscle be cut across, the detached portion will be seen to advance in the fluid by a spontaneous motion, like the tentaculum of a polype, under

Gasteropoda, or inhabitants of univalve shells, this opening is usually wide. In the *Acephala*, or bivalve mollusca, the gills are spread out, in the form of laminæ, round the margin of the shell, as exemplified in the oyster, where it is commonly known by the name of *beard*. The aerated water is admitted through a fissure in the mouth, and when it has performed its office in respiration, is usually expelled by a separate opening. The part of the mouth through which the water is admitted to the branchiæ is sometimes prolonged, forming a tube, open at the extremity, and at all times allowing free ingress and egress to the water, even when the animal has withdrawn its body wholly within its shell. Sometimes one, and sometimes two tubes of this kind are met with; and they are often protected by a tubular portion of shell, as is seen in the *Murex*, *Buccinum*, and *Strombus;* in other instances, the situation of the tube is only marked by a deep notch in the edge of the shell. In those mollusca which burrow in the sand, this tube can be extended to a considerable length, so as to reach the water, which is alternately sucked in and ejected by the muscular action of the mouth. In those Acephala which are unprovided with any tube of this kind, the mechanism of respiration consists simply in the opening and shutting of the shell. By watching them attentively, we may perceive that the surrounding water is moved in an eddy by these actions, and that the current is kept up without interruption. All the Sepiæ have their gills enclosed in two lateral cavities, which communicate with a funnel-shaped opening in the middle of the neck, and alternately receiving and expelling the water by the muscular action of its sides. The forms assumed by the respiratory organs in this class are almost infinitely diversified, while the general design of their arrangement is still the same.

As we rise in the scale of animals, the respiratory func-

the same circumstances. Similar currents of water, according to the recent observations of Mr. Listar, and apparently determined by the same mechanism of vibratory cilia, take place in the branchial sac of Ascidiæ.

tion assumes a higher importance. In fishes the gills form large organs, and the continuance of their action is more essential to life than it appears to be in any of the inferior classes: they are situated, as is well known, on each side of the throat in the immediate vicinity of the heart. Their usual form is shown at G G, Fig. 366, where they are repre-



sented on one side only, but in their relative situations with respect to the auricle (D,) and ventricle (E,) of the heart; the bulbus arteriosus (b,) and the branchial artery (F.) They have the same fringed structure as in the mollusca, the fibres being set close to each other, like the barbs of a feather, or the teeth of a fine comb, and being attached on each side of the throat, in double rows, to the convex margins of four cartilaginous or osseous arches, which are themselves connected with the jaws by the bone called the *os hyoides*. The mode of their articulation is such as to allow each arch to have a small motion forwards, by which they are separated from one another; and by moving backwards they are again brought together, or collapsed. Each filament contains a slender plate of cartilage, giving it mechanical support, and enabling it to preserve its shape while moved by the streams of water which are perpetually rushing past. When their surfaces are still more minutely examined, they are found to be covered with innumerable minute processes, crowded together like the pile of velvet; and on these are distributed myriads of blood vessels, spread like a delicate net-work, over every part of the surface. The whole extent of this surface exposed to the action of the aerated water, by these thickly set filaments, must be exceedingly great.*

A large flap termed the *Operculum*, extends over the whole organ, defending it from injury, and leaving below a wide fissure for the escape of the water, which has performed its office in respiration. For this purpose the water is taken in by the mouth, and forced by the muscles of the throat through the apertures which lead to the branchial cavities: in this action the branchial arches are brought forwards, and separated to a certain distance from each other; and the rush of water through them unfolds and separates each of the thousand minute filaments of the branchiæ, so that they all receive the full action of that fluid as it passes by them. Such appears to be the principal mechanical object of the act of respiration in this class of animals; and it is an object that requires the co-operation of a liquid such as water, capable of acting by its impulsive momentum in expanding every part of the apparatus on which the blood vessels are distributed. When a fish is taken out of the water, this effect can no longer be produced; in vain the animal reiterates its utmost efforts to raise the branchiæ, and relieve the sense of suffocation it experiences in consequence of the general collapse of the filaments of those organs, which adhere together in a mass, and can no longer receive the vivifying influence of oxygen.† Death is, in like manner, the consequence of a ligature passed round the fish, and preventing the expansion of the branchiæ and the motion of the *opercula*.

* Dr. Monro computed that in the skate, the surface of the gills is, at the least, equal to the whole surface of the human body.

† It has been generally stated by physiologists, even of the highest authority, such as Cuvier, that the principal reason why fishes cannot maintain

In all osseous fishes the opening under the operculum for the exit of the respired water, is a simple fissure; but in most of the cartilaginous tribes, there is no operculum, and the water escapes through a series of apertures in the side of the throat. Sharks have five oblong orifices of this description, as may be seen in Fig. 367.*

As the *Lamprey* employs its mouth more constantly than other fish in laying hold of its prey, and adhering to other bodies, the organs of respiration are so constructed as to be independent of the mouth in receiving the water. There are seven external openings on each side (Fig. 368,) leading into the same number of separate oval pouches, situated horizontally, and the inner membrane of which has the same structure as gills: these pouches are seen on a larger scale than in the preceding figure, in Fig. 369. There is also an equal number of internal openings, seen in the lower part of this last figure, leading into a tube, the lower end of which is closed and the upper terminates by a fringed edge in the œsophagus. The water which is received by the seven lateral openings, enters at one side, and after it has acted upon the gills, passes round the projecting membranes. The greater part makes its exit by the same orifices; but a portion escapes into the middle tube, and thence passes, either into the other cavities, or into the œsophagus.†

life, when surrounded by air instead of water, is that the branchiæ become dry, and lose the power of acting when thus deprived of their natural moisture; for it might otherwise naturally be expected that the oxygen of atmospheric air would exert a more powerful action on the blood which circulates in the branchiæ, than that of merely aerated water. The rectification of this error is due to Flourens, who pointed out the true cause of suffocation, stated in the text, in a Memoir entitled "Expériences sur le Méchanisme de la Respiration des Poissons."—Annales des Sciences Naturelles, xx. 5.

* They are also visible in Fig. 293, (page 122,) which is that of the *Squalus pristis*, a species belonging to this tribe.

† It was commonly supposed that the respired water is ejected through the nostril; but this is certainly a mistake, for the nostril has no communication with the mouth, as was pointed out by Sir E. Home. Philos. Trans. for 1815, p. 259. These organs have also been described by Bloch and Gærtner.

In the *Myxine*, which feeds upon the internal parts of its prey, and buries its head and part of its body in the flesh, the openings of the respiratory organs are removed sufficiently far from the head to admit of respiration going on while the animal is so employed; and there are only two external openings, and six lateral pouches on each side, with tubes similar to those in the lamprey.

The *Perca scandens* (Daldorff,*) which is a fish inhabiting the seas of India, has a very remarkable structure adapting it to the maintenance of respiration, and consequently to the support of life for a considerable time when out of the water; and hence it is said occasionally to travel on land to some distance from the coast.† The pharyngeal bones of this fish have a foliated and cellular structure, which gives them a capacity for retaining a sufficient quantity of water, not only to keep the gills moist, but also to enable them to perform their proper office; while not a particle of water is suffered to escape from them, by the opercula being accurately closed.

The same faculty, resulting from a similar structure, is possessed by the *Ophicephalus*, which is also met with in the lakes and rivers of India and China. Eels are enabled to carry on respiration when out of water, for a certain period, in consequence of the narrowness of the aperture for the exit of the water from the branchial cavity, which enables it to be closed, and the water to be retained in that cavity.‡

I have already stated that, in all aquatic animals, the water which is breathed is merely the vehicle by which the air it contains is brought into contact with the organs of respiration. This air is constantly vitiated by the respiration of these animals, and requires to be renewed by the absorption of a

* *Anthias testudinus* (Bloch:) *Anabs* (Cuv.)

† This peculiar faculty has been already alluded to in volume i. p. 301.

‡ Dr. Hancock states that the *Doras costatus*, (*Silurus costatus*, Linn.) or Hassar, in very dry seasons, is sometimes seen, in great numbers, making long marches over land in search of water. Edin. Phil. Journal, xx. 396.

fresh portion, which can only take place when the water freely communicates with the atmosphere; and if this renewal be by any means prevented, the water is no longer capable of sustaining life. Fishes are killed in a very few hours, if confined in a limited portion of water, which has no access to fresh air. When many fishes are enclosed in a narrow vessel, they all struggle for the uppermost place, (where the atmospheric air is first absorbed,) like the unfortunate men imprisoned in the black-hole at Calcutta. When a small fish pond is frozen over, the fishes soon perish, unless holes be broken in the ice, in order to admit air: they may be seen flocking towards these holes, in order to receive the benefit of the fresh air as it is absorbed by the water; and so great is their eagerness on these occassions, that they often allow themselves to be caught by the hand. Water from which all air has been extracted, either by the air-pump, or by boiling, is to fishes what a vacuum is to a breathing terrestrial animal. Humboldt and Provençal made a series of experiments on the quantities of air which fishes require for their respiration. They found that river-water generally contains about one-36th of its bulk of air, of which quantity one-third consists of oxygen, being about one per cent., of the whole volume. A tench is able to breathe when the quantity of oxygen is reduced to the 5000th part of the bulk of the water, but soon becomes exceedingly feeble by the privation of this necessary element. The fact, however, shows the admirable perfection of the organs of this fish, which can extract so minute a quantity of air from water to which that air adheres with great tenacity.*

* The swimming bladder of fishes is regarded by many of the German naturalists as having some relations to the respiratory function, and as being the rudiment of the pulmonary cavity of land animals; the passage of communication with the œsophagus being conceived to represent the trachea. The air contained in the swimming bladder of fishes has been examined by many chemists, but although it is generally found to be a mixture of oxygen and nitrogen, the proportion in which these gases exist is observed to vary considerably. Biot concluded from his experiments, that in the air-

§ 3. *Atmospheric Respiration.*

The next series of structures which are to come under our review, comprehends all those adapted to the respiration of atmospheric air in its gaseous form; and their physiology is no less diversified than that of the organs by which water is respired.

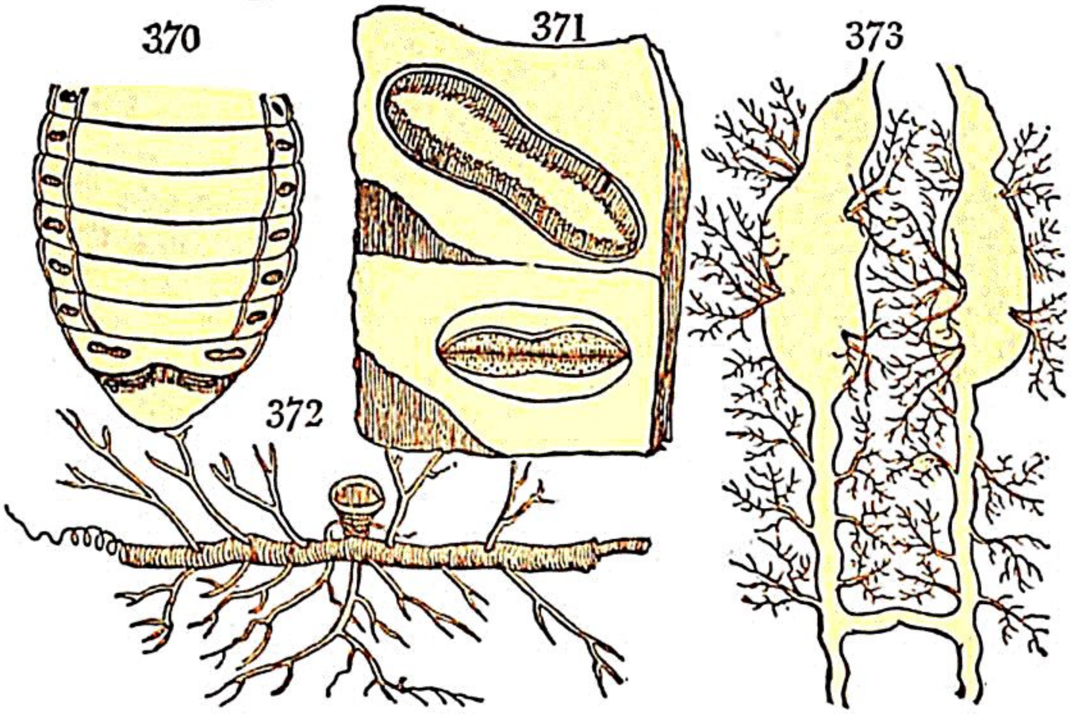
Air may be respired by *tracheæ*, or by *pulmonary cavities;* the first mode is exemplified in insects; the second is that adopted in the larger terrestrial animals.

The greater part of the blood of insects being diffused by transudation through every internal organ of their bodies, and a small portion only being enclosed in vessels, and circulating in them, the salutary influence of the air could not have been generally extended to that fluid by any of the ordinary modes of respiration, where the function is carried on in an organ of limited extent. As the blood could not be brought to the air, it became necessary, therefore, that the air should be brought to the blood. For this purpose, there has been provided in all insects, a system of continuous and ramified vessels, called *tracheæ*, distributing air to every part of the body. The external orifices, from which these air tubes commence, are called *spiracles*, or *stigmata*, and

bladder of fishes inhabiting the greatest depths of the ocean, the quantity of oxygen is greater, while in those of fishes which come often to the surface, the nitrogen is more abundant; and De la Roche came to the same conclusion from his researches on the fishes of the Mediterranean. From the experiments of Humboldt and Provençal, on the other hand, we may conclude, that the quality of the air contained in the air-bladder is but remotely connected with respiration. (Mémoires de la Société d'Arcueil, ii. 359.)

According to Ehrmann, the *Cobitis*, or Loche, occasionally swallows air, which is decomposed in the alimentary canal, and effects a change in the blood vessels, with which it is brought into contact, exactly similar to that which occurs in ordinary respiration. It is also believed that in all fishes a partial aeration of the blood is the result of a similar action, taking place at the surface of the body under the scales of the integuments. Cuvier, sur les Poissons, I. 383.

are usually situated in rows on each side of the body, as is shown in Fig. 370, which represents the lower or abdominal



surface of the *Dytiscus marginalis*. They are seen very distinctly in the caterpillar, which has generally ten on each side, corresponding to the number of abdominal segments. In many insects we find them guarded by bristles, or tufts of hair, and sometimes by valves, placed at the orifice, to prevent the entrance of extraneous bodies. The spiracles are opened and closed by muscles provided for that purpose. Fig. 371 is a magnified view of spiracles of this description, from the *Cerambyx heros*. (Fab.) They are the beginning of short tubes, which open into large trunks, (as shown in Fig. 372,) extending longitudinally on each side, and sending off radiating branches from the parts which are opposite to the spiracles; and these branches are farther subdivided, in the same manner as the arteries of the larger animals, so that their minute ramifications pervade every organ in the body. This ramified distribution has frequently occasioned their being mistaken for blood vessels. In the wings of insects, the nervures, which have the appearance of veins, are only large air tubes. Jurine asserts that it is by forcing air into these tubes that the insect is enabled suddenly to expand the wings in preparing them for flight, giving them, by this means, greater buoyancy, as well as tension.

The tracheæ are kept continually pervious by a curious mechanism: they are formed of three coats, the external and internal of which are membranous; but the middle coat is constructed of an elastic thread coiled into a helix, or cylindrical spiral, (as seen in Fig. 372;) and the elasticity of this thread keeps the tube constantly in a state of expansion, and therefore full of air. When examined under water, the tracheæ have a shining silvery appearance, from the air they contain. This structure has a remarkable analogy to that of the air vessels of plants, which also bear the name of tracheæ; and in both similar variations are observed in the contexture of the elastic membrane by which they are kept pervious.*

The tracheæ, in many parts of their course, present remarkable dilatations, which apparently serve as reservoirs of air: they are very conspicuous in the *Dytiscus marginalis*, which resides principally in water; but they also exist in many insects, as the *Melolontha* and the *Cerambyx*, which live wholly in the air.† Those of the *Scolia hortorum* (Fab.) are delineated in Fig. 373, considerably magnified.

If an insect be immersed in water, air will be seen escaping in minute bubbles at each spiracle; and in proportion as the water enters into the tubes, the sensibility is destroyed. If all the spiracles be closed by oil, or any other unctuous substance, the insect immediately dies of suffocation; but if some of them be left open, respiration is kept up to a considerable extent, from the numerous communications which exist among the air vessels. Insects soon

* According to the observation of Dr. Kidd these vessels are often annular in insects, as is also the case with those of plants. He considers the longitudinal tracheæ as connecting channels, by which the insect is enabled to direct the air to particular parts for occasional purposes. Phil. Trans. for 1825, p. 234.

† Léon Dufour, Annales des Sciences Naturelles; viii. 26.

perish when placed in the receiver of an air-pump, and the air exhausted; but they are generally more tenacious of life under these circumstances than the larger animals, and often, after being apparently dead, revive on the readmission of air.

Aquatic insects have tracheæ, like those living in air, and are frequently provided with tubes, which are of sufficient length to reach the surface of the water, where they absorb air for respiration. In a few tribes a complicated mode of respiration is practised; aerated water is taken into the body, and introduced into cavities, where the air is extracted from it, and transmitted by the ordinary tracheæ to the different parts of the system.*

Such, then, is the extensive apparatus for aeration in animals, which have either no circulation of their nutritious juices, or a very imperfect one; but no sooner do we arrive at the examination of animals possessing an enlarged system of blood vessels, than we find nature abandoning the system of tracheæ, and employing more simple means of effecting the aeration of the blood. Advantage is taken of the facility afforded by the blood vessels of transmitting the blood to particular organs, where it may conveniently receive the influence of the air. Thus, Scorpions are provided, on each side of the thorax, with four pulmonary cavities, seen at L, on the left side of Fig. 374, into each of which air is admitted by a separate external opening. A, B, is the dorsal vessel, which is connected with the pulmonary cavities by means of two sets of muscles, the one set (M, M) being longer than the other (m, m, m.) The branchial arteries (V) are seen ramifying over the inner surface of the

* Mr. Dutrochet conceives that the principle on which this operation is conducted is the same with that by which gases are reciprocally transmitted through moistened membranes; as in the experiments of Humboldt and Gay Lussac, who, on enclosing mixtures of oxygen, nitrogen, and carbonic acid gases, in any proportion, in a membranous bladder, which was then immersed in aerated water, found that there is a reciprocal transit of the gases; until at length pure atmospheric air remains in the cavity of the bladder.

pulmonary cavities (R) on the right side, whence the blood is conveyed by a corresponding set of branchial veins to the dorsal vessel; and other vessels, which are ordinary

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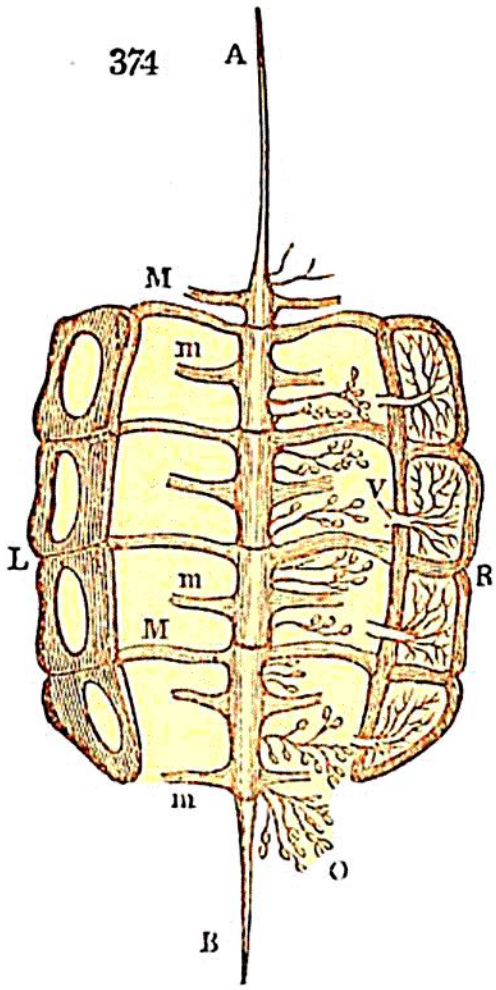

veins, are seen at O, proceeding from the abdominal cavity to join the dorsal vessel. The membrane which lines the pulmonary cavities is curiously plaited, presenting the appearance of the teeth of a comb, and partaking of the structure of gills; and on this account these organs are termed by Latreille *pneumo branchiæ*. Organs of a similar description exist in Spiders, some species having eight, others four, and some only two: but there is one entire order of Arachnida which respire by means of tracheæ, and in these the circulation is as imperfect as it is in insects.

It may here be remarked that an essential difference exists in the structure of the respiratory organs, according to the nature of the medium which is to act upon them: for in aquatic respiration the air contained in water is made to act on the blood circulating in vessels which ramify on the external surface of the filaments of the gills; while in atmospheric respiration the air in its gaseous state is always received into cavities, on the internal surface of which the blood vessels, intended to receive its influence, are distributed. It is not difficult to assign the final cause of this change of plan; for in each case the structure is accommodated to the mechanical properties of the medium respired. A liquid, being inelastic and ponderous, is adapted, by its momentum alone, to separate and surround the loose floating filaments composing the branchiæ; but a light gaseous fluid, like air, is, on the contrary, better fitted to expand dilatable cavities into which it may be introduced.

Occasionally, however, it is found that organs constructed like branchiæ, and usually performing aquatic respiration, can be adapted to respire air. This is the case with some species of Crustacea, of the order *Decapoda*, such as Crabs, which, by means of a peculiar apparatus, discovered by Audouin, and Milne Edwards, retain a quantity of water in the branchial cavity so as to enable them to live a very long time out of the water. It is only in their mature state of development, however, that they are qualified for this amphibious existence, for at an early period of growth they can live only in water.

There is an entire order of Gasteropodus Mollusca which breathe atmospheric air by means of pulmonary cavities. This is the case with the *Limax*, or slug, and also with the *Helix*, or snail, the *Testacella*, the *Clausilia*, and many others, which, though partial to moist situations, are, from the conformation of their respiratory organs, essentially land animals. The air is received by a round aperture near the head, guarded by a sphincter muscle, which is seen to dilate or contract as occasion may require, but which is sometimes completely concealed from view by the mouth folding over it. The cavity, to which this opening leads, is lined with a membrane delicately folded, and overspread with a beautiful net-work of pulmonary vessels. Other mollusca of the same order, which are more aquatic in their habits, have yet a similar structure, and are obliged at intervals to come to the surface of the water in order to breathe atmospheric air: this is the case with the *Onchidium*, the *Planorbis*, the *Lymnæa*, &c.

The structure of the pulmonary organs becomes gradually more refined and complicated as we ascend to the higher classes of animals. In all vertebrated terrestrial animals they are called *lungs*, and consist of an assemblage of vesicles, into which the air is admitted by a tube, called the *trachea*, or wind-pipe, extending downwards from the back of the mouth, parallel to the œsophagus. Great care is taken to guard the beginning of this passage from the intrusion of any solid or liquid that may be swallowed. A cartilaginous valve, termed the *epiglottis*, is generally provided for this purpose, which is made to descend by the action of the same muscles that perform deglutition, and which then closes accurately the entrance into the air-tube. It is an exceedingly beautiful contrivance, both as to the simplicity of the mechanism, and the accuracy with which it accomplishes the purpose of its formation. At the upper part of the chest the trachea divides into two branches, called the *bronchia*, passing to the lungs on either side. Both the wind-pipe and the bronchia are prevented from closing by the interposition of a series of firm cartilaginous ringlets, interposed between their inner and outer coats, and placed at small and equal distances from one another. The natural elasticity of these ringlets tends to keep the sides of the tube stretched, and causes it to remain open: it is a structure very analogous to that of the trachea of insects, or of the vessels of the same name in plants.

The lungs of Reptiles consist of large sacs, into the cavity of which the bronchia, proceeding from the bifurcation of the trachea, open at once, and without farther subdivision. Cells are formed within the sides of this great cavity, by fine membranous partitions, as thin and delicate as soap bubbles. The lungs of serpents have scarcely any of these partitions, but consist of one simple pulmonary sac, situated on the right side, having the slender elongated form of all the other viscera, and extending nearly the whole length of the body. The lung on the left side is in general scarcely discernible, being very imperfectly developed. In the chameleon the lungs have numerous processes which project from them like cæca. In the Sauria, the lungs are more confined to the thoracic region, and are more completely cellular.

The mechanism, by which, in these animals, the air is forced into the lungs, is exceedingly peculiar, and was for a long time a subject of controversy. If we take a frog as an example, and watch its respiration, we cannot readily discover that it breathes at all, for it never opens its mouth to receive air, and there is no motion of the sides to indicate that it respires; and yet, on any sudden alarm, we see the animal blowing itself up, as if by some internal power, though its mouth all the while continues to be closed. We may perceive, however, that its throat is in frequent motion, as if the frog were economizing its mouthful of air, and transferring it backwards and forwards between its mouth and lungs; but if we direct our attention to the nostrils, we may observe in them a twirling motion, at each movement of the jaws; for it is, in fact, through the nostrils that the frog receives all the air which it breathes. The jaws are never opened but for eating, and the sides of the mouth form a sort of bellows, of which the nostrils are the inlets; and by their alternate contraction and relaxation the air is swallowed, and forced into the trachea, so as to inflate the lungs. If the mouth of a frog be forcibly kept open, it can no longer breathe, because it is deprived of the power of swallowing the air required for that function; and if its nostrils be closed, it is, in like manner, suffocated. The respiration of most of the Reptile tribes is performed in a similar manner; and they may be said rather to swallow the air they breathe, than to draw it in by any expansive action of the parts which surround the cavity of the lungs; for even the ribs of serpents contribute but little, by their motion, to this effect, being chiefly useful as organs of progression.

The Chelonia have lungs of great extent, passing backwards under the carapace, and reaching to the posterior part of the abdomen. Turtles, which are aquatic, derive great advantages from this structure, which enables them to give buoyancy to their body, (encumbered as it is with a heavy shell,) by introducing into it a large volume of air; so that the lungs, in fact, serve the purposes of a large swimming bladder. That this use was contemplated in their structure is evident from the volume of air received into the lungs, being much greater than is required for the sole purpose of respiration. The section of the lungs of the turtle (Fig. 375,) shows their anterior structure, composed of large cells, into which the trachea (T) opens.

T

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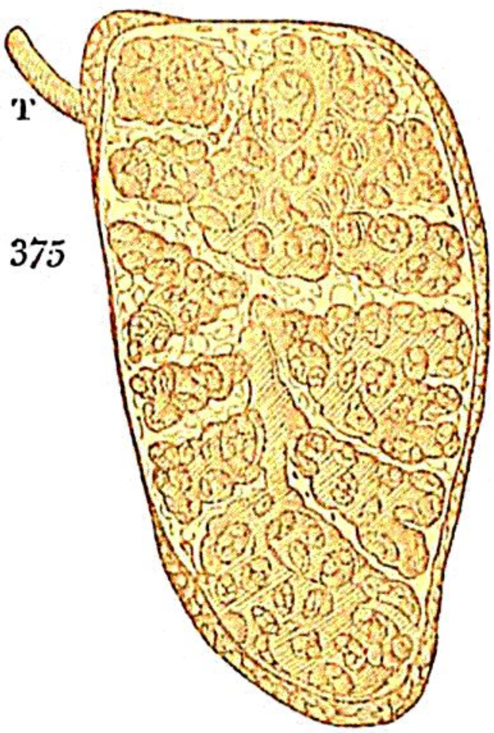

Few subjects in animal physiology are more deserving the attention of those whose object is to trace the operations of nature in the progressive development of the organs, than the changes which occur in the evolution of the tadpole from the time it leaves the egg till it has attained the form of the perfect frog. We have already had occasion to notice several of these transformations in the organs of the mechanical functions, and also in those of digestion and circulation: but the most remarkable of all are the changes occurring in the respiratory apparatus, corresponding with the opposite nature of the elements which the same animal is destined to inhabit in the different stages of its existence. No less than three sets of organs are provided for respiration; the first two being branchiæ, adapted to the fish-like condition of the tadpole, and the last being pulmonary cavities, for receiving air, to be employed when the animal exchanges its aquatic for its terrestrial life. It is exceedingly interesting to observe that this animal at first breathes by gills, which project in an arborescent form from the sides of the neck, and float in the water; but these structures are merely temporary, being provided only to meet the immediate exigency of the occasion, and being raised at a period when none of the internal organs are as yet perfected. As soon as another set of gills, situated internally, can be constructed, and are ready to admit the circulating blood, the external gills are superseded in their office; they now shrivel, and are removed, and the tadpole performs its respiration by means of branchiæ, formed on the model of those fishes, and acting by a similar mechanism. By the time that the system has undergone the changes necessary for its conversion into the frog, a new and very different apparatus has been evolved for the respiration of air. These are the lungs, which gradually coming into play, direct the current of blood from the branchiæ, and take upon themselves the whole office of respiration. The branchiæ, in their turn, become useless, are soon obliterated, and leave no other trace of their former existence than the original division of the arterial trunks, which had supplied them with blood directly from the heart, but which, now uniting in the back, form the descending aorta.*

There is a small family called the *Perenni-branchia*, belonging to this class, which, instead of undergoing all the

* See Fig. 357, p. 197.

changes I have been describing, present, during their whole lives, a great similitude to the first stage of the tadpole. This is the case with the *Axolotl*, the *Proteus anguinus*, the *Siren lacertina*, and the *Menobranchus lateralis*, which permanently retain their external gills, while at the same time they possess imperfectly developed lungs. It would therefore seem as if, in these animals, the progress of development had been arrested by nature at an early stage, so that their adult state corresponds to the larva condition of the frog.*

In all warm-blooded animals respiration becomes a function of much greater importance, the continuance of life being essentially dependent on its vigorous and unceasing exercise. The whole class of Mammalia have lungs of an exceedingly developed structure, composed of an immense number of minute cells crowded together as closely as possible, and presenting a vast extent of internal surface. The thorax, or cavity in which the lungs, together with the heart and its great blood vessels, are enclosed, has somewhat the shape of a cone; and its sides are defended from compression by the arches of the ribs, which extend from the spine to the sternum, or breast-bone, and produce mechanical support on the same principle that a cask is strengthened by being girt with hoops, which, though composed of comparatively weak materials, are yet capable, from their circular shape, of presenting great resistance to any compressing force.

While Nature has thus guarded the chest, with such peculiar solicitude, against the efforts of any external force, tending to diminish its capacity, she has made ample provision for enlarging or contracting its diameter in the act of

* Geoffroy St. Hilaire thinks there is ground for believing that Crocodiles and Turtles possess, in addition to the ordinary pulmonary respiration, a partial aquatic abdominal respiration, effected by means of the two channels of communication which have been found to exist between the cavity of the abdomen and the external surface of the body: and also that some analogy may be traced between this aquatic respiration in reptiles, by these *peritoneal canals*, and the supposed function of the swimming bladder of fishes, in subserviency to a species of aerial respiration.

respiration. First, at the lower part, or that which corresponds to the basis of the cone, the only side, indeed, which is not defended by bone, there is extended a thin expansion, partly muscular, and partly tendinous, forming a complete partition, and closing the cavity of the chest on the side next to the abdomen. This muscle is called the *Diaphragm:* it is perforated, close to its origin from the spine, by four tubes, namely, the œsophagus, the aorta, the vena cava, and the thoracic duct. Its surface is not flat, but convex above, or towards the chest; and the direction of its fibres is such, that, when they contract, they bring down the middle part, which is tendinous, and render it more flat than before, (the passage of the four tubes already mentioned, not interfering with this action,) and thus, the cavity of the thorax may be considerably enlarged. It is obvious that if, upon the descent of the diaphragm, the lungs were to remain in their original situation, an empty space would be left between them and the diaphragm. But no vacuum can take place in the body; the air cells of the lungs must always contain, even in their most compressed state, a certain quantity of air; and this air will tend, by its elasticity, to expand the cells: the lungs will, consequently, be dilated, and will continue to fill the chest; and the external air will rush in through the trachea in order to restore the equilibrium. This action is termed *inspiration*. The air is again thrown out when the diaphragm is relaxed, and pushed upwards, by the action of the large muscles of the trunk; the elasticity of the sides of the chest, concur in producing the same effect; and thus *expiration* is accomplished.

The muscles which move the ribs conspire also to produce dilatations and contractions of the cavity of the chest. Each rib is capable of a small degree of motion on that extremity by which it is attached to the spine; and this motion, assuming the chest to be in the erect position, as in man, is chiefly upwards and downwards. But, since the inclination of the ribs is such that their lower edges form acute angles with the spine, they bend downwards as they proceed towards the breast; and the uppermost rib being a fixed point, the action of the intercostal muscles, which produces an approximation of the ribs, tends to raise them, and to bring them more at right angles with the spine; the sternum, also, to which the other extremities of the ribs are articulated, is elevated by this motion, and, consequently, removed to a greater distance from the spine; the general result of all these actions is to increase the capacity of the chest.

Thus, there are two ways in which the cavity of the thorax may be dilated; namely, by the action of the diaphragm, and by the action of the intercostal muscles. It is only in peculiar exigencies that the whole power of this apparatus is called into action; for in ordinary respiration the

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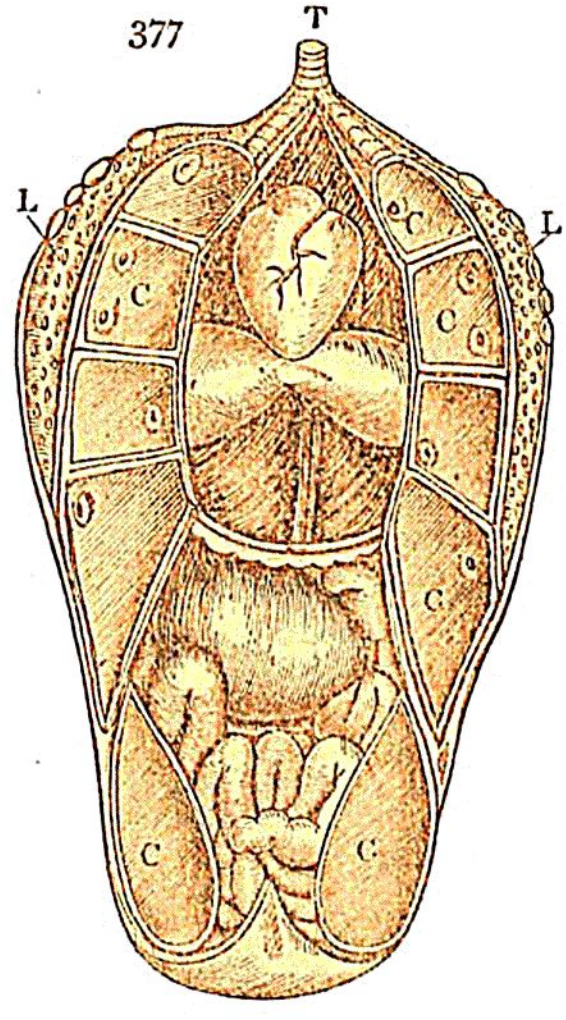

diaphragm is the chief agent employed, and the principal effect of the action of the intercostal muscles is simply to fix the ribs, and thus give greater purchase to the diaphragm. The muscles of the ribs are employed chiefly to assist the diaphragm, when, from any cause, a difficulty arises in dilating the chest.

In Birds the mechanism of respiration proceeds upon a different plan, of which an idea may be derived from the view given of the lungs of the *Ostrich*, at L. L., Fig. 377. The construction of the lungs of birds is such as not to admit of any change in their dimensions; for they are very compact in their texture, and are so closely braced to the ribs, and upper parts of the chest, by firm membranes, as to preclude all possibility of motion. They in part, indeed, project behind the intervals between the ribs, so that their whole mass is not altogether contained within the thoracic cavity. There is no large muscular diaphragm by which any change in the capacity of the chest could be effected, but merely a few narrow slips of muscles, arising from the inner sides of the ribs, and inserted into the thin transparent membrane which covers the lower surface of the lungs. They have the effect of lessening the concavity of the lungs towards the abdomen at the time of inspiration, and they thereby assist in dilating the air-cells.* The bronchia, or divisions of the trachea (T,) after opening, as usual, into the pulmonary air-cells, do not terminate there, but pass on to the surface of the lungs, where they open by numerous apertures. The air is admitted, through these apertures, into several large air-cells (c c c,) which occupy a considerable portion of the body, and which enclose most of the large viscera contained in the abdomen, such as the liver, the stomach, and the intestines;† and there are, besides, many lateral cells in immediate communication with the lungs, and extending all down the sides of the body. Numerous air-cells also exist between the muscles, and underneath the skin; and the air penetrates even into the interior of the bones themselves, filling the spaces usually occupied by the marrow, and thus contributing ma-

* Hunter on the Animal Economy, p. 78.

† It was asserted by the Parisian Academicians, that the air gets admission into the cavity of the pericardium, in which the heart is lodged. This error was first pointed out by Dr. Macartney. See Rees's Cyclopædia.—Art. *Bird.*

terially to the lightness of the fabric.* All these cells are very large and numerous in birds which perform the highest and most rapid flight, such as the eagle. The bill of the *Toucan*, which is of a cellular structure, and also the cells between the plates of the skull in the *owl*, are, in like manner, filled with air, derived from the lungs: the barrels of the large quills of the tails and wings are also supplied with air from the same source.

In birds, then, the air is not merely received into the lungs, but actually passes through them, being drawn forwards by the muscles of the ribs when they elevate the chest, and produce an expansion of the subjacent air-cells. The chest is depressed, for the purpose of expiration, by another set of muscles, and the air driven back: this air, consequently, passes a second time through the lungs, and acts twice on the blood which circulates in those organs. It is evident that if the lungs of birds had been constructed on the plan of those of quadrupeds, they must have been twice as large to obtain the same amount of aeration in the blood; and consequently must have been twice as heavy, which would have been a serious inconvenience in an animal formed for flying.† The diffusion of so large a quantity of air throughout the body of animals of this class presents an analogy with a similar purpose apparent in the conformation of insects, where the same object is effected by means of tracheæ.‡

* In birds, not formed for extensive flight, as the gallinaceous tribes, the humerus is the only bone into which air is introduced.—Hunter on the Animal Economy, p. 81.

† I must mention, however, that the correctness of this view of the subject is contested by Dr. Macartney, who thinks it probable that the air, on its return from the large air-cells, passes directly by the large air-holes into the bronchia, and is not brought a second time into contact with the blood.

‡ The peculiarities of structure in the respiratory system of birds have probably a relation to the capability we see them possess, of bearing with impunity, very quick and violent changes of atmospheric pressure. Thus, the Condor of the Andes is often seen to descend rapidly from a height of above 20,000 feet, to the edge of the sea, where the air is more than twice

Thus, has the mechanism of respiration been varied in the different classes of animals, and adapted to the particular element, and mode of life designed for each. Combined with the peculiar mode of circulation, it affords a tolerably accurate criterion of the energy of the vital powers. In birds, the muscular activity is raised to the highest degree, in consequence of the double effect of the air upon the whole circulating blood in the pulmonary organs. The Mammalia rank next below birds, in the scale of vital energy; but they still possess a double circulation, and breathe atmospheric air. The torpid and cold-blooded reptiles are separated from mammalia by a very wide interval, because, although they respire air, that air only influences a part of the blood; the pulmonary, being only a branch of the general circulation. In fishes, again, we have a similar result, because, although the whole blood is brought by a double circulation to the respiratory organs, yet it is acted upon only by that portion of air which is contained in the water respired, and which is less powerful in its action than the same element in its gaseous state. We may, in like manner, continue to trace the connexion between the extent of these functions and the degrees of vital energy throughout the successive classes of invertebrate animals. The vigour and activity of the functions of insects, in particular, have an evident relation to the effective manner in which the complete aeration of the blood is secured by an extensive distribution of tracheæ through every part of their system.

§ 4. *Chemical Changes effected by Respiration.*

We have next to direct our attention to the chemical offices which respiration performs in the animal economy. It

the density of that which the bird had been breathing. We are, as yet, unable to trace the connexion which probably exists between the structure of the lungs, and this extraordinary power of accommodation to such great and sudden variations of atmospheric pressure.

is only of late years that we may be said to have obtained any accurate knowledge as to the real nature of this important function; and there is perhaps no branch of physiology which exhibits in its history a more humiliating picture of the wide sea of error in which the human intellect is prone to lose itself, when the path of philosophical induction is abandoned, than the multitude of wild and visionary hypotheses, devoid of all solid foundation, and perplexed by the most inconsistent reasonings, which formerly prevailed with regard to the objects and the processes of respiration. To give an account, or even a brief enumeration of these theories, now sufficiently exploded, would be incompatible with the purpose to which I must confine myself in this treatise.* I shall content myself, therefore, with a concise statement of such of the leading facts relating to this function, as have now, by the labours of modern physiologists, been satisfactorily established, and which serve to elucidate the beneficent intentions of nature in the economy of the animal system.

Atmospheric air acts without difficulty upon the blood while it is circulating through the vessels which are ramified over the membranes lining the air cells of the lungs; for neither these membranes, nor the thin coats of the vessels themselves, present any obstacle to the transmission of chemical elements from the one to the other. The blood being a highly compound fluid, it is exceedingly difficult to obtain an accurate analysis of it, and still more to ascertain with precision the different modifications which occur in its chemical condition at different times: on this account, it is scarcely possible to determine, by direct observation, what are the exact chemical changes, which that fluid undergoes

* For an account of the history of the various chemical theories which have prevailed on this interesting department of Physiology, I must refer to the "Essay on Respiration," by Dr. Bostock, and also to the "Elementary System of Physiology," by the same author, which latter work comprises the most comprehensive and accurate compendium of the science that has yet appeared.

during its passage through the lungs; and we have only collateral evidence to guide us in the inquiry.*

The most obvious effect resulting from the action of the air is a change of colour from the dark purple hue, which the blood has when it is brought to the lungs, to the bright vermilion colour, which it is found to assume in those organs, and which accompanies its restoration to the qualities of arterial blood. In what the chemical difference between these two states consists may, in some measure, be collected from the changes which the air itself, by producing them, has experienced.

The air of the atmosphere, which is taken into the lungs, is known to consist of about twenty per cent. of oxygen gas, seventy-nine of nitrogen gas, and one of carbonic acid gas. When it has acted upon the blood, and is returned from the lungs, it is found that a certain proportion of the oxygen, which it had contained, has disappeared, and that the place of this oxygen is almost wholly supplied by an addition of carbonic acid gas, together with a quantity of watery vapour. It appears also probable that a small portion of the nitrogen gas is consumed during respiration.

For our knowledge of the fact of the disappearance of oxygen we are indebted to the labours of Dr. Priestley. It had, indeed, been long before suspected by Mayow, that some portion of the air inspired is absorbed by the blood; but the merit of the discovery that it is the oxygenous part of the air which is thus consumed is unquestionably due to Dr.

* Some experiments very recently made by Messrs. Macaire and Marcet, on the ultimate analysis of arterial and venous blood, taken from a rabbit, and dried, have shown that the former contains a larger proportion of oxygen than the latter; and that the latter contains a larger proportion of carbon than the former: the proportions of nitrogen and hydrogen being the same in both. The following are the exact numbers expressive of these proportions:

	Carbon.	*Oxygen.*	*Nitrogen.*	*Hydrogen.*
Arterial blood	50.2	26.3	16.3	6.6
Venous blood	55.7	21.7	16.2	6.4

Mémoires de la Société de Physique et d'Hist. Naturelle de Geneve. T. v. p. 400.

Priestley. The exact quantity of oxygen, which is lost in natural respiration, varies in different animals, and even in different conditions of the same animal. Birds, for instance, consume larger quantities of oxygen by their respiration; and hence require, for the maintenance of life, a purer air than other vertebrated animals. Vauquelin, however, found that many species of insects and worms possess the power of abstracting oxygen from the atmosphere in a much greater degree than the larger animals. Even some of the terrestrial mollusca, such as snails, are capable of living for a long time in the vitiated air in which a bird had perished. Some insects, which conceal themselves in holes, or burrow under ground, have been known to deprive the air of every appreciable portion of its oxygen. It is observed by Spallanzani, that those animals, whose modes of life oblige them to remain for a great length of time in these confined situations, possess this power in a greater degree than others, which enjoy more liberty of moving in the open air: so admirably have the faculties of animals been, in every instance, accommodated to their respective wants.

Since carbonic acid consists of oxygen and carbon, it is evident that the portion of that gas which is exhaled from the lungs is the result of the combination of either the whole or a part, of the oxygen gas, which disappears during the act of respiration, with the carbon contained in the dark venous blood, which is brought to the lungs. The blood having thus parted with its superabundant carbon, which escapes in the form of carbonic acid gas, regains its natural vermilion colour, and is now qualified to be again transmitted to the different parts of the body for their nourishment and growth. As the blood contains a greater proportion of carbon than the animal solids and fluids which are formed from it, this superabundant carbon gradually accumulates in proportion as its other principles, (namely, oxygen, hydrogen, and nitrogen) are abstracted from it by the processes of secretion and nutrition. By the time it has returned to the heart, therefore, it is loaded with carbon, a principle, which, when in excess, becomes noxious, and requires to be removed from the blood, by combining it with a fresh quantity of oxygen obtained from the atmosphere. It is not yet satisfactorily determined whether the whole of the oxygen, which disappears during respiration, is employed in the formation of carbonic acid gas: it appears, probable, however, from the concurring testimony of many experimentalists, that a small quantity is permanently absorbed by the blood, and enters into it as one of its constituents.

A similar question arises with respect to nitrogen, of which as I have already mentioned, it is probable that a small quantity disappears from the air when it is respired; although the accounts of experimentalists are not uniform on this point. The absorption of nitrogen during respiration was one of the results which Dr. Priestley had deduced from his experiments: and this fact, though often doubted, appears, on the whole, to be tolerably well ascertained by the inquiries of Davy, Pfaff, and Henderson. With regard to the respiration of cold-blooded animals, it has been satisfactorily established by the researches of Spallanzani, and more especially by those of Humboldt and Provençal, on fishes, that nitrogen is actually absorbed. A confirmation of this result has recently been obtained by Messrs. Macaire and Marcet, who have found that the blood contains a larger proportion of nitrogen than the chyle, from which it is formed. We can discover no other source from which chyle could acquire this additional quantity of nitrogen, during its conversion into blood, than the air of the atmosphere, to which it is exposed in its passage through the pulmonary vessels.*

According to these views of the chemical objects of respiration, the process itself is analogous to those artificial operations which effect the combustion of charcoal. The food supplies the fuel, which is prepared for use by the di-

* See the note at page 238.

gestive organs, and conveyed by the pulmonary arteries to the place where it is to undergo combustion: the diaphragm is the bellows, which feeds the furnace with air; and the trachea is the chimney, through which the carbonic acid, which is the product of the combustion, escapes.

It becomes an interesting problem to determine whether this analogy may not be farther extended; and whether the combustion of carbon, which takes place in respiration, be not the exclusive source of the increased temperature, which all animals, but more especially those designated as *warm-blooded*, usually maintain above the surrounding medium. The uniform and exact relation which may be observed to take place between the temperature of animals and the energy of the respiratory function, or, rather, the amount of the chemical changes induced by that function, affords very strong evidence in favour of this hypothesis. The coincidence, indeed, is so strong, that notwithstanding the objections that have been raised against the theory founded upon this hypothesis, from some apparent anomalies which occasionally present themselves, we must, I think, admit that it affords the best explanation of the phenomena of any theory yet proposed, and that, therefore, it is probably the true one.

The maintenance of a very elevated temperature appears to require the concurrence of two conditions; namely, first, that the whole of the blood should be subjected to the influence of the air, and, secondly, that that air should be presented to it in a gaseous state. These, then, are the circumstances which establish the great distinction between warm and cold-blooded animals; a distinction which at once stamps the character of their whole constitution. It is the condition of a high temperature in the blood which raises the quadruped and the bird to a rank, in the scale of vitality, so far above that of the reptile: it is this which places an insuperable boundary between mammalia and fishes. However the warm-blooded Cetacea, who spend their lives in the ocean, may be found to approximate in their outward form, and in their external instruments of motion, to the other inhabitants of the deep, they are still, from the conformation of their respiratory organs, dependent on another element. If a seal, a porpoise, or a dolphin were confined, but for a short time, under the surface of the water, it would perish with the same certainty as any other of the mammalia, placed in the same situation. We observe them continually rising to the surface in order to breathe, under every circumstance of privation or of danger; and however eagerly they may pursue their prey, however closely they may be pressed by their enemies, a more urgent want compels them, from time to time, to respire air at the surface of the sea. Were it not for this imperious necessity, the Whale, whose enormous bulk is united with corresponding strength and swiftness, would live in undisturbed possession of the widely extended domains of the ocean, might view, without dismay, whole fleets sent out against him, and might defy all the efforts that man could practise for his capture or destruction. But the constitution of his blood, obliging him to breathe at the surface of the water, brings him within the reach of the fatal harpoon. In vain, on feeling himself wounded, does he plunge for refuge into the recesses of the deep; the same necessity recurs, and compelling him again to present himself to his foes, exposes him to their renewed attacks, till he falls in the unequal struggle. His colossal form and gigantic strength are of little avail against the power of man, feeble though that power may seem, when physically considered, but which derives resistless might from its association with an immeasurably superior intellect.

CHAPTER XII.

SECRETION.

The capability of effecting certain chemical changes in the crude materials introduced into the body, is one of the powers which more especially characterize life; but although this power is exercised both by vegetable and by animal organizations, we perceive a marked difference in the results of its operation in these two orders of beings. The food of plants consists, for the most part, of the simpler combinations of elementary bodies, which are elaborated in cellular or vascular textures, and converted into various products. The oak, for example, forms, by the powers of vegetation, out of these elements, not only the green pulpy matter of its leaves, and the light tissue of its pith, but also the densest of its woody fibres. It is from similar materials, again, that the olive prepares its oil, and the cocoa-nut its milk; and the very same elements in different states of combination, compose, in other instances, at one time the luscious sugar of the cane, at another the narcotic juice of the poppy, or the acrid principle of the euphorbium; and the same plant which furnishes in one part the bland farina of the potato, will produce in another the poisonous extract of the nightshade. Yet all these, and thousands of other vegetable products, differing widely in their sensible qualities, agree very nearly in their ultimate chemical analysis, and owe their peculiar properties chiefly to the order in which their elements are arranged; an order dependent on the processes to which they have been subjected in the system of each particular vegetable.

In the animal kingdom we observe these processes multiplied to a still greater extent; and the resulting substances are even farther removed from the original condition of unorganized matter. In the first place, the food of animals, instead of being simple, like that of plants, has always undergone previous preparation; for it has either constituted a portion of some other organized being, or it has been a product of organization; in each case, therefore, partaking of that complexity of composition which characterizes organized bodies. Still, whatever may be its qualities when received into the stomach, it is soon converted by the powers of digestion into a milky, or transparent fluid, having nearly the same uniform properties. We have seen that there is scarcely any animal or vegetable substance, however dense its texture, or virulent its qualities, but is capable of affording nourishment to various species of animals. Let us take as an example the elytra of cantharides, which are such active stimulants when applied in powder to the skin in the ordinary mode of blistering: we find that, notwithstanding their highly acrid qualities, they constitute the natural food of several species of insects, which devour them with great avidity; and yet the fluids of these insects, though derived from this pungent food, are perfectly bland, and devoid of all acrimony. Cantharides are also, according to Pallas, the favourite food of the hedge-hog; although to other mammalia they are highly poisonous. It has also been found that even those animal secretions, (such as the venom of the rattle-snake,) which, when infused into a wound, even in the minutest quantity, prove quickly fatal, may be taken into the stomach without producing any deleterious effects. These, and a multitude of other well-known facts, fully prove how completely substances received as aliment may be modified, and their properties changed, or even reversed, by the powers of animal digestion.

No less remarkable are the transmutations, which the blood itself, the result of these previous processes, is subsequently made to undergo in the course of circulation, and when subjected to the action of the nutrient vessels and secreting organs; being ultimately converted into the various textures and substances which compose all the parts of the animal frame. All the modifications of cellular substance, in its various states of condensation; the membranes, the ligaments, the cartilages, the bones, the marrow; the muscles, with their tendons; the lubricating fluid of the joints; the medullary pulp of the brain; the transparent jelly of the eye; in a word, all the diversified textures of the various organs, which are calculated for such different offices, are derived from the same nutrient fluid, and may be considered as being merely modified arrangements of the same ultimate chemical elements.

In what, then, we naturally ask, consists this subtle chemistry of life, by which nature effects these multifarious changes; and in what secret recesses of the living frame has she constructed the refined laboratory in which she operates her marvellous transformations, far surpassing even those which the most visionary alchemist of former times had ever dreamed of achieving? Questions like these can be fairly met only by the confession of profound ignorance; for, although the subject of secretion has long excited the most ardent curiosity of physiologists, and has been prosecuted with extraordinary zeal and perseverance, scarcely any positive information has resulted from their labours, and the real nature of the process remains involved in nearly the same degree of obscurity as at first.* It was natural to ex-

* It is not yet precisely determined to what extent the organs of secretion are immediately instrumental in producing the substance secreted; and it has been even suggested that possibly their office is confined to the mere separation, or filtration from the blood, of certain animal products, which are always spontaneously forming in that fluid in the course of its circulation. This hypothesis, in which the glands, and other secreting apparatus are regarded as only very fine strainers, is supported by a few facts, which seem to indicate the presence of some of these products in the blood, independently of the secreting processes by which they are usually supposed to be formed; but the evidence is as yet too scanty and equivocal to warrant the deduction of any general theory on the subject.

pect that in this inquiry material assistance would be derived from an accurate anatomical examination of the organs by which the more remarkable secretions are formed; yet, notwithstanding the most minute and careful scrutiny of these organs, our knowledge of the mode in which they are instrumental in effecting the operations which are there conducted, has not in reality advanced a single step. To add to our perplexity, we often see, on the one hand, parts, to all appearance very differently organized, giving rise to secretions of a similar nature; and, on the other hand, substances of very different properties produced by organs, which, even in their minutest details, appear to be identical in their structure. Secretions are often found to be poured out from smooth and membranous surfaces, such as those which line the cavities of the abdomen, the chest, and the head, and which are also reflected inwards, so as to invest the organs therein contained, as the heart, the lungs, the stomach, the intestines, the liver, and the brain.* In other instances, the secreting membrane is thickly set with minute processes, like the pile of velvet: these processes are called *villi*, and their more obvious use, as far as we can perceive, is to increase the surface from which the secretion is prepared. At other times we see an opposite kind of structure employed; the secreting surface being the internal lining of sacs or cells, either opening at once into some larger cavity, or prolonged into a tube, or duct, for convey-

* Sometimes the secreting organ appears to be entirely composed of a mass of vessels covered with a smooth membrane; in other cases, it appears to contain some additional material, or *parenchyma* as it is termed. Vertebrated animals present us with numerous instances of glandular organs employed for special purposes of secretion: thus, in the eyes of fishes there exists a large vascular mass, which has been called the *choroid gland*, and which is supposed to be placed there for the purpose of replenishing some of the humours of the eye, in proportion as they are wasted. Within the air-bladder of several species of fishes there is found a vascular organ, apparently serving to secrete the air with which the bladder is filled; numerous ducts, filled with air, having been observed proceeding from the organ, and opening on the inner surface of the air-bladder.

ing the secreted fluid to a more distant point. These cells, or *follicles*, as they are termed, are generally employed for the mucous secretions, and are often scattered throughout the surfaces of membranes:* at other times the secreting cavities are collected in great numbers into groups; and they then frequently consist of a series of lengthened tubes, like cæca, examples of which we have already seen in the hepatic and salivary glands of insects.

A secretory organ, in its simplest form, consists of short, narrow and undivided tubes; we next find tubes which are elongated, tortuous or convoluted, occasionally presenting dilated portions, or even having altogether the appearance of a collection of pouches, or sacs; while, in others cases, they are branched, and extend into minute ramifications. Sometimes they are detached, or isolated; at other times they are collected into tufts, or variously grouped into masses, where still the separate tubes admit of being unravelled. The secreting filaments of insects float in the general cavity, containing the mass of nutrient fluid, and thence imbibe the materials they require for the performance of their functions. It is only when they receive a firm investment of cellular membrane, forming what is termed a *capsule*, and assuming the appearance of a compact body, that they properly constitute a *gland;* and this form of a secreting organ is met with only among the higher animals.†

Great variety is observable both in the form and structure of different glands, and in the mode in which their blood vessels are distributed. In animals which are furnished with an extensive circulation, the vessels supplying the glands with blood are distributed in various modes; and it is evident that each plan has been designedly selected with reference to the nature of the particular secretion to

* See p. 135 of this volume; and in particular Fig. 305. Sebaceous follicles are also noticed in Vol. i. p. 19.

† Dr. Kidd, however, describes bodies apparently of a glandular character, disposed in rows on the inner surface of the intestinal canal of the *Gryllotalpa*, or mole-cricket. Phil. Tran. for 1825, p. 227.

be performed, although we are here unable to follow the connexion between the means and the end. In some glands, for example, the minute arteries, on their arrival at the organ, suddenly divide into a great number of smaller branches, like the fibres of a camel-hair pencil: this is called the *penicillated* structure. Sometimes the minute branches, instead of proceeding parallel to each other after their division, separate like rays from a centre, presenting a *stellated*, or star-like arrangement. In the greater number of instances, the smaller arteries take a tortuous course, and are sometimes coiled into spirals, but generally the convolutions are too intricate to admit of being unravelled. It is only by the aid of the microscope that these minute and delicate structures can be rendered visible; but the fallacy, to which all observations requiring the application of high magnifying powers are liable, is a serious obstacle to the advancement of our knowledge in this department of physiology. Almost the only result, therefore, which can be collected from these laborious researches in microscopic anatomy, is that nature has employed a great diversity of means for the accomplishment of secretion; but we still remain in ignorance as to the kind of adaptation, which must assuredly exist, of each structure to its respective object, and as to the nice adjustment of chemical affinities which has been provided in order to accomplish the intended effects.* Elec-

* The only instance in which we can perceive a correspondence between the chemical properties of the secretion, and the kind of blood from which it is prepared, is in the liver, which, unlike all the other glands, has venous, instead of arterial blood, sent to it for that purpose. The veins, which return the blood that has circulated through the stomach, and other abdominal viscera, are collected into a large trunk, called the *vena portæ*, which enters the liver, and is there again subdivided and ramified, as if it were an artery: its minuter branches here unite with those of the hepatic artery, and ramify through the minute lobules which compose the substance of the liver. After the bile is secreted, and carried off by hepatic ducts, the remaining blood is conducted, by means of minute hepatic veins, which occupy the centres of each lobule, into larger and larger trunks, till they all unite in the vena cava, going directly to the heart. (See Kiernan's Paper on the Anatomy and Physiology of the Liver, Phil. Trans. for 1833, p. 711.) A similar system of ve-

tricity is, no doubt, an important agent in all these processes, but in the absence of all certain knowledge as to the mode in which it is excited and brought into play in the living body, the chasm can for the present be supplied only by remote conjecture.

The process which constitutes the ultimate stage of nutrition, or the actual incorporation of the new material with the solid substance of the body, of which it is to form a part, is involved in equal obscurity with that of secretion.

nous ramifications, though on a much smaller scale, has been discovered by Jacobson, in the kidneys of most fishes and reptiles, and even in some birds.

CHAPTER XIII.

ABSORPTION.

Absorption is another function, related to nutrition, which deserves special notice. The principal objects of this function are the removal of such materials as have been already deposited, and have become either useless or injurious, and their conveyance into the general mass of circulating fluids; purposes which are accomplished by a peculiar set of vessels, called the *Lymphatics*. These vessels contain a fluid, which being transparent and colourless like water, has been denominated the *lymph*. The lymphatics are perfectly similar in their structure, and probably, also, in their mode of action, to the lacteals, which absorb the chyle from the intestinal cavity: they are found in all the classes of vertebrated animals, and pervade extensively every part of the body. Exceedingly minute at their origin, they unite together as they proceed, forming larger and larger trunks, generally following the course of the veins, till they finally discharge their contents either into the thoracic duct, or into some of the large veins in the vicinity of the heart. Throughout their whole course, they are, like the lacteals, provided with numerous valves, which, when the vessel is distended with lymph, give it a resemblance to a string of beads, Fig. 378.* In the lower animals, it appears that the veins are occasionally endowed with a power of absorption, similar to that possessed

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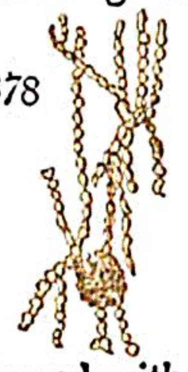

* In warm-blooded animals, the lymphatics are made to traverse, in some part of their course, certain bodies of a compact structure, resembling glands, and termed, accordingly, the *lymphatic glands*. One of these is represented

by the lymphatics. None of the invertebrata, indeed, possess lymphatics, and absorption must consequently be performed by the veins, when these latter vessels exist. The addition of the system of lymphatic vessels, as auxiliaries to the veins, may therefore be regarded as a refinement in organization, peculiar to the higher classes of animals.*

Professor Muller, of Bonn, has lately discovered that the frog, and several other amphibious animals, are provided with large receptacles for the lymph, situated immediately under the skin, and exhibiting distinct and regular pulsations, like the heart. The use of these *lymphatic hearts*, as they may be called, is evidently to propel the lymph in its proper course along the lymphatic vessels. In the frog four of these organs have been found; the two posterior hearts being situated behind the joint of the hip, and the two anterior ones on each side of the transverse process of the third vertebra, and under the posterior extremity of the scapula. The pulsations of these lymphatic hearts do not correspond with those of the sanguiferous heart; nor do those of the right and left sides take place at the same times, but they often alternate in an irregular manner. Professor Muller has discovered similar organs in the toad, the salamander, and the green lizard, and thinks it probable that they exist in all the amphibia.†

in Fig. 378. They correspond in structure, and probably also in their functions, to the mesenteric glands, through which, in the mammalia, the lacteals pass, before reaching the thoracic duct. It is chiefly in the mammalia, indeed, that these glands are met with; for they are rare among birds, and still more so among fishes and reptiles.

* Fohmann, who has made extensive researches on the absorbent vessels throughout all the classes of vertebrated animals, has found that they terminate extensively in the veins. See his work, entitled "Anatomische Untersuchungen uber die Verbindung der Saugadern mit den Venen."

† Phil. Trans. for 1833, p. 89.

CHAPTER XIV.

NERVOUS POWER.

The organs which are appropriated to the performance of the various functions conducive to nutrition, are generally designated the *vital organs*, in order to distinguish them from those which are subservient to sensation, voluntary motion, and the other functions of *animal life*. The slightest reflection on the variety and complication of actions comprised under the former class of functions in the higher animals, will convince us that they must be the result of the combined operation of several different agents; but the principal source of mechanical force required by the vital organs, is still, as in all other cases, the muscular power. The coats of the stomach and of the intestinal tube contain a large proportion of muscular fibres, the contractions of which effect the intermixture and propulsion of the contents of these cavities, in the manner best calculated to favour the chemical operations to which they are to be subjected, and to extract from them all the nourishment they may contain. In like manner, all the tubular vessels, which transmit fluids, are endowed with muscular powers adapted to the performance of that office. The heart is a strong hollow muscle, with power adequate to propel the blood, with immense force, through the arterial, and venous systems. The blood vessels, also, especially the minute, or capillary arteries, besides being elastic, are likewise endowed with muscular power, which contributes its share in forwarding the motion of the blood, and completing its circulation. The quantity of blood circulating in each part, the velocity of its motion, and the heat which it evolves, are regulated in a great measure by the particular mode of action of the blood vessels of that part. The quantity, and sometimes even the quality of the secretions, are dependent, in like manner, on the conditions of the circulation; and the action of the ducts, which convey the secreted fluids to their respective destinations, is also resolvable into the effects of a muscular power.

The immediate cause which, in these organs, excites the muscular fibre to contraction, may frequently be traced to the forcible stretching of its parts. This is the case in all hollow and tubular muscles, such as the stomach, the heart, and the blood vessels, when they are mechanically distended, beyond a certain degree, by the presence of contained fluids, or other substances. At other times, the chemical quality of their contents appears to be the immediate stimulus inciting them to contraction. But numerous instances occur, in the higher orders of animals, in which these causes alone are inadequate to explain the phenomena of the vital functions. No mechanical hypothesis will suffice to account for the infinite diversity in the modes of action of the organs which perform these functions, or afford any clew to the means by which they are made to co-operate, with such nicety of adjustment, in the production of the ultimate effect. Still less will any theory, comprising only the agency of the muscular power, and the ordinary chemical affinities, enable us to explain how an irritating cause, applied at one part, shall produce its visible effects on a distant organ; or in what way remote and apparently unconnected parts shall, as if by an invisible sympathy, be brought, at the same moment, to act in concert, in the production of a common effect. Yet such co-operation must, in innumerable cases, be absolutely indispensable to the perfect accomplishment of the vital functions of animals.

Nature has not neglected objects so important to the success of her measures, but has provided, for the accomplishment of these purposes, a controlling faculty, residing in the nervous system, and denominated the *nervous power*. Experiments have shown that the due performance of the vital functions of digestion, of circulation, and of secretion, requires the presence of an agency, derived from different parts of the brain and spinal marrow, and regulating the order and combinations of the actions of the organs which are to perform those functions. The same influence, for example, which increases the power of secretion in any particular gland, is found to increase, at the same time, the action of those blood vessels which supply that gland with the materials for secretion; and conversely, the increased action of the blood vessels is accompanied by an increased activity of the secreting organ. Experience also shows that when the influence of the brain and spinal marrow is intercepted, although the afflux of blood may, for a time, continue, yet the secretion ceases, and all the functions dependent upon secretion, such as digestion, cease likewise. Thus, the nervous power combines together different operations, adjusts their respective degrees, and regulates their succession, so as to ensure that perfect harmony which is essential to the attainment of the objects of the vital functions; and thus, not only the muscular power which resides in the vital organs, but also the organic affinities which produce secretion, and all those unknown causes which effect the nutrition, development, and growth of each part, are placed under the control of the nervous power.*

Although we are entirely ignorant of the nature of the nervous power, we know that, when employed in the vital functions, it acts through the medium of a particular set of fibres, which form part of the nervous system, and are classed, therefore, among the nerves. The principal filaments of this class of nerves compose what is called the *sympathetic nerve,* from its being regarded as the medium of extensive

* As the functions of plants are sufficiently simple to admit of being conducted without the aid of muscular power, still less do they require the assistance of the nervous energy; both of which properties are the peculiar attributes of animal vitality. We accordingly find no traces either of nervous or of muscular fibres in any of the vegetable structures.

sympathies among the organs; but the whole assemblage of these nerves is more commonly known by the name of the *ganglionic system*, from the circumstance of their being connected with small masses of nervous substance, termed *ganglia*, which are placed in different parts of their course. Fig. 379, represents a ganglion (G,) through which the

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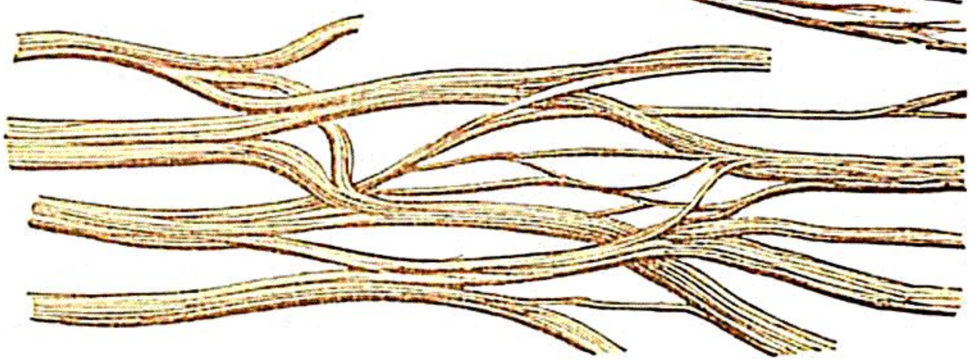

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nerve (N,) consisting at its origin of a number of separate filaments (F,) is seen to pass, before it subdivides into branches (B.) The numerous communications and interchanges of filaments, which subsequently take place at various parts, forming what is called a *plexus*, are shown in Fig. 380: where four trunks (T, T,) divide into branches, which are again separated, and variously reunited in their course, like a ravelled skein of thread, before they proceed to their respective destinations.

The ganglia are connected by nervous filaments with every part of the brain and spinal marrow, the great central organs of the nervous system; and they also send out innumerable branches, to be distributed all over the body. All the parts receiving blood vessels, and more especially the organs of digestion, are abundantly supplied with ganglionic nerves; so that, by their intervention, all these parts have extensive connexions with the brain and spinal marrow, and also with one another. The ganglia are more particularly the points of union between nervous fibres coming from many different parts: they may be considered, therefore, as performing, with regard to the vital functions, an office analogous to that which the brain and spinal marrow perform with regard to the other nerves, or as being secondary centres of nervous power. Thus, there are two important objects for which the nerves belonging to the ganglionic system have been provided; first, to serve as the channels through which the affections of one organ might be enabled to influence a distant organ; and secondly, to be the medium through which the powers of several parts might be combined and concentrated for effecting particular purposes, requiring such co-operation. Hence it is by means of the ganglionic nerves that all the organs and all the functions are rendered efficient in the production of a common object, and are brought into one comprehensive and harmonious system of operation.

The nervous power, the effects of which we are here considering, should be carefully distinguished from that power which is an attribute of another portion of the nervous system, and which, being connected with sensation, volition, and other intellectual operations, has been denominated *sensorial power*.* The functions of digestion, circulation, absorption, secretion, and all those included under the class of nutrient or vital functions, are carried on in secret, are not necessarily, or even usually attended with sensation, and are wholly removed from the control of volition. Nature has not permitted processes, which are so important to the preservation of life, to be in any way interfered with by the will of the animal. We know that in ourselves they go on as well during sleep as when we are awake, and whether our attention be directed to them or not; and though occasionally influenced by strong emotions, and other affections of mind, they are in general quite independent of every intellectual process. In the natural and healthy condition of

* This distinction has been most clearly pointed out and illustrated by Dr. A. P. W. Philip. See his "Experimental Inquiry into the Laws of the Vital Functions."

the system all its internal operations proceed quietly, steadily, and constantly, whether the mind be absorbed in thought or wholly vacant. The kind of existence resulting from these functions alone, and to which our attention has hitherto been confined, must be regarded as the result of mere vegetative, rather than of animal life. It is time that we turn our views to the higher objects, and more curious field of inquiry, belonging to the latter.

PART III.

THE SENSORIAL FUNCTIONS.

CHAPTER I.

SENSATION.

The system of mechanical and chemical functions which we have been occupied in reviewing, has been established only as a *foundation for the endowment of those higher faculties* which constitute the great objects of animal existence. It is in the study of these final purposes that the scheme of nature, in the formation of the animal world, opens and displays itself in all its grandeur. The whole of the phenomena we have hitherto considered concur in one essential object, the maintenance of a simply vital existence. Endowed with these properties alone, the organized system would possess all that is absolutely necessary for the continuance and support of mere vegetative life. The machinery provided for this purpose is perfect and complete in all its parts. To raise it to this perfection, not only has the Divine Architect employed all the properties and powers of matter, which science has yet revealed to man, but has also brought into play the higher and more mysterious energies of nature, and has made them to concur in the great work that was to be performed. On the organized fabric there has been conferred a vital force; with the powers of mechanism have been conjoined those of chemistry; and to these have been superadded the still more subtle and potent agencies of caloric and of electricity: every resource has been employed, every refinement practised, every combination exhausted that could ensure the stability, and prolong the duration of the system, amidst the multifarious causes which continually menace it with destruction. It has been supplied with ample means of repairing the accidents to which it is ordinarily exposed; it has been protected from the injurious influence of the surrounding elements, and fitted to resist for a lengthened period the inroads of disease, and the progress of decay.

But can this, which is mere physical existence, be the sole end of life? Is there no farther purpose to be answered by structures so exquisitly contrived, and so bountifully provided with the means of maintaining an active existence, than the mere accumulation and cohesion of inert materials, differing from the stones of the earth only in the more artificial arrangement of their particles, and the more varied configuration of their texture? Is the growth of an animal to be ranked in the same class of phenomena as the concretion of a pebble, or the crystallization of a salt? Must we not ever associate the power of feeling with the idea of animal life? Can we divest ourselves of the persuasion that the movements of animals directed like our own, to obvious ends, proceed from voluntary acts, and imply the operation of an intellect, not wholly dissimilar in its spiritual essence from our own? In vain may Descartes and his followers labour to sustain their paradox, that brutes are only automata,—mere pieces of artificial mechanism, insensible either to pleasure or to pain, and incapable of internal affections, analogous to those of which we are conscious in ourselves. Their sophistry will avail but little against the plain dictates of the understanding. To those who refuse to admit that enjoyment, which implies the powers of sensation, and of voluntary motion, is the great end of animal existence, the object of its creation must for ever remain a dark and impenetrable mystery; by such minds must all farther inquiry into final causes be at once abandoned as utterly vain and hopeless. But it surely requires no laboured refutation to overturn a system that violates every analogy by which our reasonings on these subjects must necessarily be guided; and no artificial logic or scholastic jargon will long prevail over the natural sentiment, which must ever guide our conduct, that animals possess powers of feeling, and of spontaneous action, and faculties appertaining to those of intellect.

The functions of sensation, perception, and voluntary motion require the presence of an animal substance, which we find to be organized in a peculiar manner, and endowed with very remarkable properties. It is called the *medullary substance;* and it composes the greater part of the texture of the brain, spinal marrow, and nerves; organs, of which the assemblage is known by the general name of *the nervous system.* Certain affections of particular portions of this medullary substance, generally occupying some central situation, are, in a way that is totally inexplicable, connected with affections of the sentient and intelligent principle; a principle which we cannot any otherwise conceive than as being distinct from matter; although we know that it is capable of being affected by matter operating through the medium of this nervous substance, and that it is capable of reacting upon matter through the same medium. Of the truth of these propositions there exist abundant proofs; but as the evidence which establishes them will more conveniently come under our notice at a subsequent period of our inquiry, I shall postpone their consideration; and proceeding upon the assumption that this connexion exists, shall next inquire into the nature of the intervening steps in the process, of which sensation and perception are the results.

Designating, then, by the name of *brain* this primary and essential organ of sensation, or the organ of which the physical affections are immediately attended by that change in the percipient being which we term *sensation;* let us first inquire what scheme has been devised for enabling the brain to receive impressions from such external objects, as it is intended that this sentient being shall be capable of perceiving. As these objects can, in the first instance, make impressions only on the organs situated at the surface of the body, it is evidently necessary that some medium of communication should be provided between the external organ and the brain. Such a medium is found in the *nerves*, which are white cords, consisting of bundles of threads or filaments of medullary matter, enveloped in sheaths of membrane, and extending continuously from the external organ to the brain, where they all terminate. It is also indispensably requisite that these notices of the presence of objects should be transmitted instantly to the brain; for the slightest delay would be attended with serious evil, and might even lead to fatal consequences. The nervous power, of which, in our review of the vital functions, we noticed some of the operations, is the agent employed by nature for this important office of a rapid communication of impressions. The velocity with which the nerves subservient to sensation transmit the impressions they receive at one extremity, along their whole course, to their termination in the brain, exceeds all measurement, and can be compared only to that of electricity passing along a conducting wire.

It is evident, therefore, that the brain requires to be furnished with a great number of these nerves, which perform the office of conductors of the subtle influence in question; and that these nerves must extend from all those parts of the body which are to be rendered sensible, and must unite at their other extremities in that central organ. It is of especial importance that the surface of the body, in particular, should communicate all the impressions received from the contact of external bodies, and that these impressions should produce the most distinct perceptions of touch. Hence, we find that the skin, and all those parts of it more particularly intended to be the organs of a delicate touch, are most abundantly supplied with nerves; each nerve, however, communicating a sensation distinguishable from that of every other, so as to enable the mind to discriminate between them, and refer them to their respective origins in different parts of the surface. It is also expedient that the internal organs of the body should have some sensibility; but it is better that this should be very limited in degree, since the occasions are few in which its exercise would be useful, and many in which it would be positively injurious: hence, the nerves of sensation are distributed in less abundance to these organs.

It is not sufficient that the nerves of touch should communicate the perceptions of the simple pressure or resistance of the bodies in contact with the skin: they should also furnish indications of other qualities in those bodies, of which it is important that the mind be apprized; such, for example, as warmth, or coldness. Whether these different kinds of impressions are all conveyed by the same nervous fibres, it is difficult, and, perhaps, impossible to determine.

When these nerves are acted upon in a way which threatens to be injurious to the part impressed, or to the system at large, it is also their province to give warning of the impending evil, and to rouse the animal to such exertions as may avert it; and this is effected by the sensation of pain, which the nerves are commissioned to excite on all these occasions. They act the part of sentinels, placed at the outposts, to give signals of alarm on the approach of danger.

Sensibility to pain must then enter as a necessary constituent among the animal functions; for, had this property been omitted, the animal system would have been but of short duration, exposed, as it must necessarily be, to perpetual casualties of every kind. Lest any imputation should be attempted to be thrown on the benevolent intentions of the great Author and Designer of this beautiful and wondrous fabric, so expressly formed for varied and prolonged enjoyment, it should always be borne in mind that the occasional suffering, to which an animal is subjected from this law of its organization, is far more than counterbalanced by the consequences arising from the capacities for pleasure, with which it has been beneficently ordained that the healthy exercise of the functions should be accompanied. Enjoyment appears universally to be the main end, the rule, the ordinary and natural condition; while pain is but the casualty, the exception, the necessary remedy, which is ever tending to a remoter good, in subordination to a higher law of creation.

It is a wise and bountiful provision of nature that each of the internal parts of the body has been endowed with a particular sensibility to those impressions which, in the ordinary course, have a tendency to injure its structure; while it has, at the same time, been rendered nearly, if not completely, insensible to those which are not injurious, or to which it is not likely to be exposed. Tendons and ligaments, for example, are insensible to many causes of mechanical irritation, such as cutting, pricking, and even burning: but the moment they are violently stretched, that being the mode in which they are most liable to be injured, they instantly communicate a feeling of acute pain. The bones, in like manner, scarcely ever communicate pain in the healthy state, except from the application of a mechanical force which tends to fracture them.

The system of nerves, comprising those which are designed to convey the impressions of touch, is universally present in all classes of animals; and among the lowest orders, they appear to constitute the sole medium of communication with the external world. As we rise in the scale of animals, we find the faculties of perception extending to a wider range, and many qualities, depending on the chemical action of bodies, are rendered sensible, more especially those which belong to the substances employed as food. Hence arises the sense of taste, which may be regarded as a new and more refined species of touch. This difference in the nature of the impressions to be conveyed, renders it necessary that the structure of the nerves, or, at least, of those parts of the nerves which are to receive the impression, should be modified and adapted to this particular mode of action.

As the sphere of perception is enlarged, it is made to comprehend, not merely those objects which are actually in contact with the body, but also those which are at a distance, and of the existence and properties of which it is highly important that the animal, of whose sensitive faculties we are examining the successive endowment, should be apprized. It is more especially necessary that he should acquire an accurate knowledge of the distances, situations, and motions of surrounding objects. Nature has accordingly provided suitable organizations for vision, for hearing, and for the perception of odours; all of which senses establish extensive relations between him and the external world, and give him the command of various objects which are necessary to supply his wants, or procure him gratification; and which also apprize him of danger while it is yet remote, and may be avoided. Endowed with the power of combining all these perceptions, he commences his career of sensitive and intellectual existence; and though he soon learns that he is dependent for most of his sensations on the changes which take place in the external world, he is also conscious of an internal power, which gives him some kind of control over many of those changes, and that he moves his limbs by his own voluntary act; movements which originally, and of themselves, appear in most animals, to be productive of great enjoyment.

To a person unused to reflection, the phenomena of sensation and perception may appear to require no elaborate investigation. That he may behold external objects, nothing more seems necessary than directing his eyes towards them. He feels as if the sight of those objects were a necessary consequence of the motion of his eye-balls, and he dreams not that there can be any thing marvellous in the function of the eye, or that any other organ is concerned in this simple act of vision. If he wishes to ascertain the solidity of an object within his reach, he knows that he has but to stretch forth his hand, and to feel in what degree it resists the pressure he gives to it. No exertion even of this kind is required for hearing the voices of his companions, or being apprized, by the increasing loudness of the sound of falling waters, as he advances in a particular direction, that he is coming nearer and nearer to the cataract. Yet how much is really implied in all these apparently simple phenomena! Science has taught us that these perceptions of external objects, far from being direct or intuitive, are only the final results of a long series of operations, produced by agents of a most subtle nature, which act by curious and complicated laws, upon a refined organization, disposed in particular situations in our bodies, and adjusted with admirable art to receive their impressions, to modify and combine them in a certain order, and to convey them in regular succession, and without confusion, to the immediate seat of sensation.

Yet this process, complicated as it may appear, constitutes but the first stage of the entire function of *perception;* for before the mind can arrive at a distinct knowledge of the presence and peculiar qualities of the external object which gives rise to the sensation, a long series of mental changes must intervene, and many intellectual operations must be performed. All these take place in such rapid succession, that even when we include the movement of the limb, which is consequent upon the perception, and which we naturally consider as part of the same continuous action, the whole appears to occupy but a single instant. Upon a careful analysis of the phenomena, however, as I shall afterwards attempt to show, we find that no less than twelve distinguishable kinds of changes, or rather processes, some of which imply many changes, must always intervene, in regular succession, between the action of the external object on the organ of sense, and the voluntary movement of the limb which it excites.

The external agents, which are capable of affecting the different parts of the nervous system, so as to produce sensation, are of different kinds, and are governed by laws peculiar to themselves. The structure of the organs must, accordingly, be adapted, in each particular case, to receive the impressions made by these agents, and must be modified in exact conformity with the physical laws they obey. Thus, the structure of that portion of the nervous system which receives visual impressions, and which is termed the *retina*, must be adapted to the action of light; and the eye, through which the rays are made to pass before reaching the retina, must be constructed with strict reference to the laws of optics. The ear must, in like manner, be formed to receive delicate impressions from those vibrations of the air which occasion sound. The extremities of the nerves, in these and other organs of the senses, are spread out into a delicate expansion of surface, having a softer and more uniform texture than the rest of the nerve, whereby they acquire a susceptibility of being affected by their own appropriate agents, and by no other. The function of each nerve of sense is determinate, and can be executed by no other part of the nervous system. These functions are not interchangeable, as is the case with many others in the animal system. No nerve, but the optic nerve, and no part of that nerve, except the retina, is capable, however impressed, of giving rise to the sensation of light: no part of the nervous system, but the auditory nerve, can convey that of sound; and so of the rest. The credulity of the public has sometimes been imposed upon by persons who pretended to see by means of their fingers: thus, at Liverpool, the celebrated Miss M'Avoy contrived for a long time to persuade a great number of persons that she really possessed this miraculous power. Equally unworthy of credit are all the stories of persons, under the influence of animal magnetism, hearing sounds addressed to the pit of the stomach, and reading the pages of a book applied to the skin over that organ.

In almost every case the impression made upon the sentient extremity of the nerve which is appropriated to sensation, is not the direct effect of the external body, but results from the agency of some intervening medium. There is always a portion of the organ of sense interposed between the object and the nerve on which the impression is to be made. The object is never allowed to come into direct contact with the nerves; not even in the case of touch, where the organ is defended by the cuticle, through which the impression is made, and by which that impression is modified so as to produce the proper effect on the subjacent nerves. This observation applies with equal force to the organs of taste and of smell, the nerves of which are not only sheathed with cuticle, but defended from too violent an action by a secretion expressly provided for that purpose. In the senses of hearing and of vision, the changes which take place in the organs interposed between the external impressions and the nerves, are still more remarkable and important, and will be respectively the subjects of separate inquiries. The objects of these senses, as well as those of smell, being situated at a distance, produce their first impressions by the aid of some medium exterior to our bodies, through which their influence extends; thus, the air is the usual medium through which both light and sound are conveyed to our organs. Hence, in order to understand the whole series of phenomena belonging to sensation, regard must be had to the physical laws which regulate the transmission of these agents. We are now to consider these intermediate processes in the case of each of the senses.

CHAPTER II.

TOUCH.

I HAVE already had occasion to point out the structure of the integuments, considered in their mechanical office of protecting the general frame of the body;* but we are now to view them in their relation to the sense of touch, of which they are the immediate organ. It will be recollected that the *corium* forms the principal portion of the skin; that the *cuticle* composes the outermost layer; and that between these there occurs a thin layer of a substance, termed the *rete mucosum*. The corium is constructed of an intertexture of dense and tough fibres, through which a multitude of blood vessels and nerves are interspersed; but its external surface is more vascular than any other part, exhibiting a fine and delicate net-work of vessels, and it is this portion of the skin, termed by anatomists the *vascular plexus*, which is the most acutely sensible in every point: hence we may infer that it contains the terminations of all the nervous filaments distributed to this organ, and which are here found to be divided to an extreme degree of minuteness.

When examined with the microscope, this external surface presents a great number of minute projecting filaments. Malpighi first discovered this structure in the foot of a pig; and gave these prominences the name of papillæ. It is probable that each papilla contains a separate branch of the nerves of touch, the ultimate ramifications of which are spread over the surface: so that we may consider these papillæ, of which the assemblage has been termed the *corpus papillare*, as the principal and immediate organ of

* Vol. I. p. 90.

touch. This structure is particularly conspicuous on those parts of the skin which are more especially appropriated to this sense, such as the tips of the fingers, the tongue, and the lips: in other parts of the surface, which are endowed with less sensibility, the papillæ are scarcely visible, even with the aid of the microscope.

The surface of the corium is exquisitely sensible to all irritations, whether proceeding from the contact of foreign bodies, or from the impression of atmospheric air. This extreme sensibility of the corium would be a source of constant torment, were it not defended by the cuticle, which is unprovided with either blood vessels or nerves, and is, therefore, wholly insensible. For the same reason, also, it is little liable to change, and is thus, in both respects, admirably calculated to afford protection to the finely organized corium.

Although the cuticle exhibits no traces of vascularity, it is by no means to be regarded as a dead or inorganic substance, like the shells of the mollusca. That it is still part of the living system is proved by the changes it frequently undergoes, both in the natural and the diseased conditions of the body. It is perpetually, though slowly, undergoing decay and renovation; its external surface drying off in minute scales, and in some animals peeling off in large portions. When any part of the human skin is scraped with a knife, a gray dust is detached from it, which is found to consist of minute scales.

By repeated friction, or pressure of any part of the skin, the cuticle soon acquires an increase of thickness and of hardness; this is observable in the soles of the feet, and palms of the hands, and in the fingers of those who make much use of them in laborious work. But this greater thickness in the parts designed by nature to suffer considerable pressure, is not entirely the effect of education; for the cuticle, which exists before birth, is found even then to be much thicker on the soles of the feet, and palms of the hands, than on other parts. This example of provident care in originally adjusting the structures of parts to the circumstances in which they are to be placed at an after period, would of itself, were it a solitary instance, be well fitted to call forth our admiration. But as we study each department of the animal economy in detail, the proofs of design in the adaptation of organs to their respective purposes multiply upon us in such profusion, that we are apt to overlook individual instances, unless they are particularly brought before our notice. How often have we witnessed and profited by the rapid renewal of the cuticle, when by any accident it has been destroyed, without adverting to the nature of the process which it implies; or reflected that the vessels of the skin must, on all these occasions, supply the materials, out of which the new cuticle is to be formed, must effect their combination in the requisite proportions, and must deposite them in the precise situations in which they are wanted!

Different animals present remarkable differences in the thickness and texture of the cuticle, according to the element they are destined to inhabit, and the situations in which they are most frequently placed. Provision is in many cases made for preserving the cuticle from the injury it would receive from the long continued action of the air or water; for it is apt to become rigid, and to peel off, from exposure to a very dry atmosphere; and the constant action of water, on the contrary, renders it too soft and spongy. In order to guard against both these effects, the skin has been furnished, in various parts of its surface, with a secreting apparatus, which pours out unctuous or mucilaginous fluids: the oily secretions being more particularly employed as a defence against the action of the air, and the mucilaginous fluids as a protection against that of water.

The conditions on which the perfection of the sense of touch depends are, first, an abundant provision of soft papillæ supplied with numerous nerves; secondly, a certain degree of fineness in the cuticle; thirdly, a soft cushion of cellular substance beneath the skin; fourthly, a hard resisting basis, such as that which is provided in the nails of the human fingers; and lastly, it is requisite that the organ be so constructed as to be capable of being readily applied, in a variety of directions, to the unequal surfaces of bodies; for the closer the contact, the more accurate will be the perceptions conveyed. In forming an estimate of the degree of perfection in which this sense is exercised in any particular animal, we must, accordingly, take into account the mobility, the capability of flexion, and the figure of the parts employed as organs of touch.

As touch is the most important of all the senses, inasmuch as it is the foundation of all our knowledge of the material world, so its relative degrees of perfection establish marked differences in the intellectual sagacity of the several tribes, and have a considerable influence on the assignment of their proper station in the scale of animals.

Although the power of receiving obscure impressions from the contact of external bodies, and of perceiving variations of temperature, is probably possessed by all animals, a small number only are provided with organs specially appropriated for conveying the more delicate sensations of touch. The greater part of the surface of the body in the testaceous Mollusca is protected by a hard and insensible covering of shell. The integuments of Insects, especially those of the Coleoptera, are in general too rigid to receive any fine impressions from the bodies which may come in contact with them; and the same observation applies, with even greater force, to the Crustacea. The scales of Fishes, and of Reptiles, the solid incasements of the Chelonia, the plumage of Birds, the dense coating of the Armadillo, the thick hides of the Rhinoceros, and other Pachydermata, are evidently incompatible with any delicacy of touch. This nicer faculty of discrimination can be enjoyed only by animals having a soft and flexible integument, such as all the naked Zoophytes, Worms, and Mollusca, among the lower orders, and Serpents, among the higher. The flexibility of the body or limbs is another condition which is extremely necessary towards procuring extensive and correct notions of the relative positions of external objects. It is essential therefore that those instruments which are more particularly intended as organs of touch, should possess this property.

It will not be necessary to enter into a minute description of these organs, because they have, for the most part, been already noticed as instruments of motion or prehension; for the sense of touch is in general exercised more particularly by the same parts which perform this latter function. Thus the tentacula of the various tribes of Polypi, of Actiniæ, and of Annelida, are organs both of prehension and of touch. The tubular feet of the Asterias and Echinus are subservient both to the sense of touch, and to the faculty of progressive motion. The feet of Insects and of Crustacea are well calculated, indeed, by their jointed structure, for being applied to the surfaces, and different sides of bodies: but they are scarcely ever employed in this capacity; being superseded by the palpi, which are situated near the mouth. When insects are walking, the palpi are inces-

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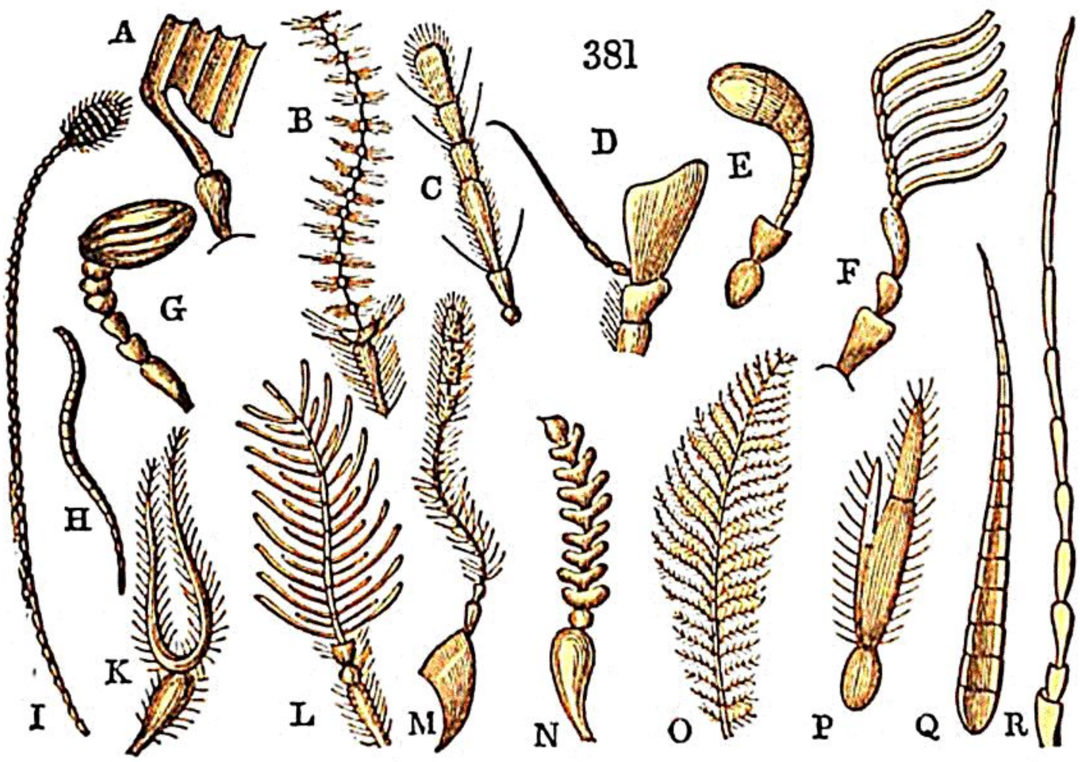


santly applied to the surface on which they advance, as if these organs were especially employed to feel their way. There can be little doubt, however, that, in most insects, the principal organs of touch are the *Antennæ*, also denominated, from their supposed office, the *feelers*.*

Some idea of the great variety in the forms of the antennæ of insects may be obtained from the specimens delineated in Fig. 381, which shows a few of the most remarkable.†

The universality of these organs among every species of this extensive class of animals, their great flexibility, arising from their jointed structure,‡ their incessant motion when the insect is walking, and their constant employment in examining the surfaces of all the bodies with which they come in contact, sufficiently point them out as instruments of a very delicate sense of touch. Organs of this kind were particularly necessary to insects, since the horny nature of the

* The German name for them, *fühlhörner*, or the *feeling horns*, is founded on the same notion.

† In this figure, A represents the form of antennæ, technically denominated *Antenna capitulo uncinato*, as exemplified in the *Pausus*.

B . is the A . piloso-verticillata, as in the *Psychoda occlaris*.
C . . A . biclavata, (*Claviger longicornis.*)
D . . A . triangularis, (*Lophosia.*)
E . . A . clavata, (*Masaris.*)
F . . A . capit. lamellato, (*Melolontha mass.*)
G . . A . capit. fissile, (*Aphodius fossor.*)
H . . A . fusiformis, (*Zygæna.*)
I . . A . capitata, (*Ascalaphus.*)
K . . A . furcata, (*Schizocera.*)
L . . A . bipectinata, (*Ctenophora.*)
M . . A . irregularis, (*Agaon paradoxum.*)
N . . A . cordata, (*Diaperis boleti.*)
O . . A . bipectinata, (*Bombyx.*)
P . . A . palmata, (*Nepa cinerea.*)
Q . . A . ensiformis, (*Truxalis.*)
R . . A . setacea, (*Cerambyx.*)

‡ The number of segments into which these organs are divided is often very great. In the *Gryllotalpa*, or mole cricket, it amounts to above 100. (Kidd, Phil. Trans. for 1825, p. 211.) This insect has, besides the antennæ on the head, two posterior or caudal antennæ, which are not jointed, excepting at their very commencement. These are extremely sensible, and serve, probably, to give the animal notice of the approach of any annoyance from behind, Ib. p. 216.

integuments of the greater number, precludes them from imparting any accurate perceptions of touch.

It has been conjectured that the antennæ of insects are the organs of other senses besides that of touch. If an insect be deprived of its antennæ, it either remains motionless, or if it attempt to walk or fly, appears bewildered, and moves without any apparent object. Huber found that bees are enabled, by feeling with their antennæ, to execute their various works in the interior of the hive, where, of course, they can have no assistance from light. They employ these organs perpetually while building the combs, pouring honey into the magazines, ascertaining the presence of the queen, and feeding and tending the larvæ. The same naturalist observes, also, that it is principally by means of the antennæ that these social insects communicate to one another their impressions and their wants.

The different modes in which ants, when they happen to meet during their excursions, mutually touch one another with their antennæ, appears to constitute a kind of natural language understood by the whole tribe. This contact of the antennæ evidently admits of a great variety of modifications, and seems capable of supplying all the kinds of information which these insects have occasion to impart. It would seem impossible, indeed, for all the individuals composing these extensive societies to co-operate effectually in the execution of many works, calculated for the general benefit of the community, unless some such means of communication existed. There is no evidence that sound is the medium of this intercourse; for none, audible to us at least, was ever known to be emitted by these insects. Their mode of communication appears to be simply by touching one another in different ways with the antennæ. Huber's observations on this subject are exceedingly curious.* He remarks that the signal denoting the apprehension of danger, is made by the ant striking its head against the corselet of

* See his "Recherches sur les mœurs des fourmis indigènes."

every ant which it chances to meet. Each ant, on receiving this intimation, immediately sets about repeating the same signal to the next ant which come in its way; and the alarm is thus disseminated with astonishing rapidity throughout the whole society. Sentinels are at all times stationed on the outside of the nests, for the purpose of apprizing the inhabitants of any danger that may be at hand. On the attack of an enemy, these guardians quickly enter into the nest, and spread the intelligence on every side: the whole swarm is soon in motion, and while the greater number of ants rush forwards with desperate fury to repel the attack, others who are intrusted with the office of guarding the eggs and the larvæ, hasten to remove their charge to places of greater security.

When the queen bee is forcibly taken away from the hive, the bees which are near her at the time do not soon appear sensible of her absence, and the labours of the hive are carried on as usual. It is seldom before the lapse of an hour, that the working-bees begin to manifest any symptoms of uneasiness: they are then observed to quit the larvæ which they had been feeding, and to run about in great agitation, to and fro, near the cell which the queen had occupied before her abduction. They then move over a wider circle, and on meeting with such of their companions as are not aware of the disaster, communicate the intelligence by crossing their antennæ, and striking lightly with them. The bees which receive the news become, in their turn, agitated, and conveying this feeling wherever they go, the alarm is soon participated by all the inhabitants of the hive. All rush forwards with tumultuous precipitation, eagerly seeking their lost queen; but after continuing the search for some hours, and finding it to be fruitless, they appear resigned to their misfortune; the noisy tumult subsides, and the bees quietly resume their labours.

A bee, deprived of its antennæ, immediately becomes dull and listless: it desists from its usual labours, remains at the bottom of the hive, seems attracted only by the light, and takes the first opportunity of quitting the hive, never more to return. A queen bee thus mutilated, ran about, without apparent object, as if in a state of delirium, and was incapable of directing her trunk with precision to the food which was offered to her. Latreille relates that, having deprived some labouring ants of their antennæ, he replaced them near the nest; but they wandered in all directions, as if bewildered, and unconscious of what they were doing. Some of their companions were seen to notice their distress; and, approaching them with apparent compassion, applied their tongues to the wounds of the sufferers, and anointed them with their saliva. This trait of sensibility was repeatedly witnessed by Latreille, while watching their movements with a magnifying glass.

The Arachnida, from the mobility of their limbs, and the thinness of their cutaneous investment, have a very delicate sense of touch. Among the Mollusca, it is only the higher orders of Cephalopoda that enjoy this sense in any considerable degree, and they are enabled to exercise it by means of their long and flexible tentacula. Many bivalve mollusca have, indeed, a set of tentacula placed near the mouth, but they are short, and of little power. It is probable that the foot may also be employed by these animals as an organ of touch.

Fishes are, in general, very ill-constructed for the exercise of this sense; and their fins are used for no other purposes than those of progressive motion. That part of the surface which possesses the most acute feeling is the underside, where the integuments are the thinnest. The chief seat of the sense of touch, however, is the lip, or end of the snout, which is largely supplied with nerves; and perhaps the *cirrhi*, or little vermiform processes called *barbels,* which in some species are appended to the mouth, may be subservient to this sense.* These processes in the *Silurus glanis* are moved by particular muscles.

* These kind of tentacula are remarkable for their length and mobility in the *Lophius piscatorius,* or Angler; and it is said that they are employed by

Serpents, from the great flexibility of their spine, are capable of grasping and twining round objects of almost any shape, and of taking, as it were, their exact measure. This conformation must be exceedingly favourable to the acquisition of correct perceptions of touch. As it is these perceptions, which, as we shall afterwards find, lay the foundation of the most perfect acquaintance with the tangible properties of surrounding bodies, we may presume that this power contributes much to the sagacity possessed by these animals. It has been said of Serpents, that their whole body is a hand, conferring some of the advantages of that instrument. Hellman has shown that the slender bifurcated tongue of these animals is used for the purposes of touch.*

In those species of Lizards which are enabled by the structure of their feet to clasp the branches of trees, as the Gecko and the Chameleon, and whose tails also are prehensile, we must, for the same reason, presume that the sense of touch exists in a more considerable degree than in other saurian reptiles, which do not possess this advantage. The toes of Birds are also well calculated to perform the office of organs of touch, from the number of their articulations and their divergent position, and from the papillæ with which their skin abounds, accompanied as they are with a large supply of nerves. Those birds, which, like the Parrot, employ the feet as organs of prehension, probably enjoy a greater development of this sense. The skin which covers the bills of aquatic birds is supplied by very large nerves, and consequently possesses great sensibility. This structure enables them to find their food, which is concealed in the mud, by the exercise of the sense of touch residing in that organ. A similar structure, probably serving a similar purpose, is found in the Ornithorhyncus.

Among Mammalia, we find the seat of this sense frequently transferred to the lips, and extremity of the nostrils, and

the fish, while lurking in ambush, as a decoy to other fishes, which they entice by their resemblance to worms.

* Quoted by Blumenbach.

many have the nose prolonged and flexible, apparently with this view. This is the case with the Shrew and the Mole, which are burrowing animals, and still more remarkably with the Pachydermata, where this greater sensibility of the parts about the face seems to have been bestowed as some compensation for the general obtuseness of feeling resulting from the thickness of the hide which covers the rest of the body. Thus, the Rhinoceros has a soft, hook-shaped extension of the upper lip, which is always kept moist, in order to preserve its sensibility as an organ of touch. The Hog has the end of the nose also constructed for feeling; though it is not so well calculated for distinguishing the form of objects, as where the organ is prolonged in the form of a snout, which it is in the Tapir, and in a still higher degree in the admirably constructed proboscis of the Elephant, which, as an organ, both of prehension and of touch, forms the nearest approach to the perfect structure of the human hand.

The Lion, Tiger, Cat, and other animals of the genus *Felis*, have whiskers, endowed at their roots with a particular sensibility, from being largely supplied with nerves. The same is the case with the whiskers of the Seal.

The prehensile tails of the American monkeys are doubtless fitted to convey accurate perceptions of touch, as well as the feet and hands; as may be inferred from the great size of the nervous papillæ, and the thinness of the cuticle of those parts.

The sense of touch attains its greatest degree of excellence in the human hand, in which it is associated with the most perfect of all instruments of prehension. But as the structure and functions of this organ are the exclusive subjects of another of these treatises, I shall refrain from any farther remarks respecting it.

CHAPTER III.

TASTE.

The senses of taste and smell are intended to convey impressions resulting from the chemical qualities of bodies, the one in the fluid, the other in the gaseous state.* There is a considerable analogy between the sensations derived from these two senses. The organ of taste is the surface of the tongue, the skin of which is furnished with a large proportion of blood vessels and nerves. The vascular plexus immediately covering the corium is here very visible, and forms a distinct layer, through which a great number of papillæ pass, and project from the surface, covered with a thin cuticle, like the pile of velvet. In the fore part of the human tongue these papillæ are visible even to the naked eye, and especially in certain morbid conditions of the organ.† They are of different kinds; but it is only those which are of a conical shape that are the seat of taste. If these papillæ be touched with a fluid, which has a strong taste, such as vinegar, applied by means of a camel-hair pencil, they will be seen to become elongated by the action of the stimulus, an effect which probably always accompanies the perception of taste.

* Bellini contended that the different flavors of saline bodies are owing to the peculiar figures of their crystalline particles. It is strange that Dumas should have thought it worth while seriously to combat this extravagant hypothesis, by a laboured refutation.

† This is particularly the case in scarlatina, in the early stage of which disease they are elongated, and become of a bright red colour, from their minute blood vessels being distended with blood. As the fever subsides, the points of the papillæ collapse, and acquire a brown hue, giving rise to the appearance known by the name of the *strawberry tongue*.

The primary use of this sense, the organ of which is placed at the entrance of the alimentary canal, is evidently to guide animals in the choice of their food, and to warn them of the introduction of a noxious substance into the stomach. With respect to the human species, this use has been, in the present state of society, superseded by many acquired tastes, which have supplanted those originally given to us by nature: but in the inferior animals it still retains its primitive office, and is a sense of great importance to the safety and welfare of the individual, from its operation being coincident with those of natural instincts. If, as it is said, these instincts are still met with among men in a savage state, they are soon weakened or effaced by civilization.

The tongue, in all the inferior classes of vertebrated animals, namely, Fishes, Reptiles, and Birds, is scarcely ever constructed with a view to the reception of delicate impressions of taste; being generally covered with a thick, and often horny cuticle; and being, besides, scarcely ever employed in mastication. This is the case, also, with those quadrupeds, which swallow their food entire, and which cannot, therefore, be supposed to have the sense of taste much developed.

Insects which are provided with a tongue or a proboscis may be conceived to exercise the sense of taste by means of these organs. But many insects possess, besides these, a pair of short feelers, placed behind the true antennæ; and it has been observed that, while the insect is taking food, these organs are in incessant motion, and are continually employed in touching and examining the food, before it is introduced into the mouth: hence, some entomologists have concluded that they are organs of taste. But it must be obvious that in this, as in every other instance in which our researches extend to beings of such minute dimensions, and which occupy a station, in the order of sensitive existence, so remote from ourselves, we are wandering into regions where the only light that is afforded us must be borrowed from vague and fanciful analogies, or created by the force of a vivid and deceptive imagination.

CHAPTER IV.

SMELL.

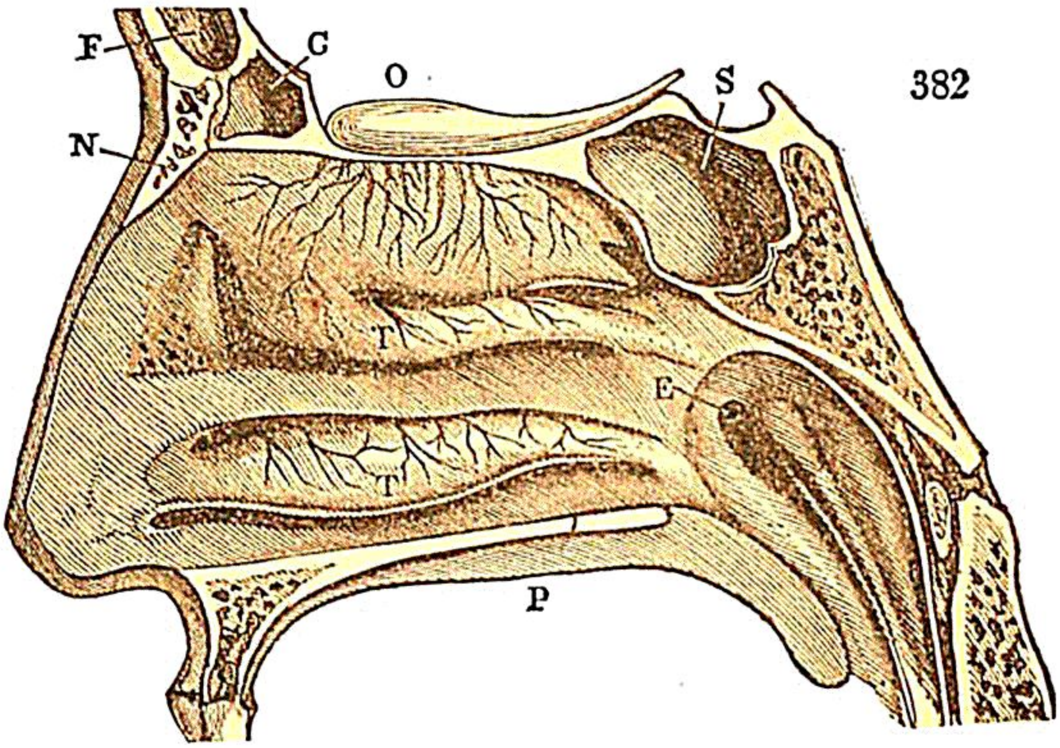
Animal life being equally dependent upon the salubrious qualities of the air respired, as of the food received, a sense has been provided for discriminating the nature of the former as well as of the latter. As the organs of taste are placed at the entrance of the alimentary canal, so those of smell usually occupy the beginning of the passages for respiration, where a distinct nerve, named the *olfactory*, appropriated to this office, is distributed.

The sense of smell is generally of greater importance to the lower animals than that of taste; and the sphere of its perceptions is in them vastly more extended than in man. The agents, which give rise to the sensations of smell, are certain effluvia, or particles of extreme tenuity, which are disseminated very quickly through a great extent of atmospheric air. It is exceedingly difficult to conceive how matter so extremely rare and subtle as that which composes these odorous effluvia can retain the power of producing any sensible impression on the animal organs: for its tenuity is so extraordinary as to exceed all human comprehension. The most copious exhalations from a variety of odoriferous substances, such as musk, valerian, or asafœtida, will be continually emanating for years, without any perceptible loss of weight in the body which supplies them. It is well known that if a small quantity of musk be enclosed for a few hours in a gold box, and then taken out, and the box cleaned as carefully as possible with soap and water, that box will retain the odour of musk for many years; and yet the nicest balance will not show the smallest increase of its weight from this impregnation. No facts in natural philosophy afford more striking illustrations of the astonishing, and indeed inconceivable divisibility of matter, than those relating to odorous effluvia.

It would appear that most animal and vegetable bodies are continually emitting these subtle effluvia, of which our own organs are not sufficiently delicate to apprize us, unless when they are much concentrated, but which are readily perceived and distinguished by the lower animals; as may be inferred from their actions. A dog is known to follow its master by the scent alone, through the avenues and turnings of a crowded city, accurately distinguishing his track amidst thousands of others.

The utility of the sense of smell is not confined to that of being a check upon the respiration of noxious gases; for it is also a powerful auxiliary to the sense of taste, which, of itself, and without the aid of smell, would be very vague in its indications and limited in its range. What may have been its extent and delicacy in man, while he existed in a savage state, we have scarcely any means of determining; but in the present artificial condition of the race, resulting from civilization and the habitual cultivation of other sources of knowledge, there is less necessity for attending to its perceptions, and our sensibility to odours may perhaps have diminished in the same proportion. It is asserted both by Soemmerring and Blumenbach that the organ of smell is smaller in Europeans, and other civilized races of mankind than in those nations of Africa or America, which are but little removed from a savage state: it is certainly much less developed in man than in most quadrupeds. To the carnivorous tribes, especially, it is highly useful in enabling them to discover their natural food at great distances.

The cavity of the nostrils, in all terrestrial vertebrated animals is divided into two by a vertical partition; and the whole of its internal surface is lined by a soft membrane, called the *Schneiderian membrane*,* which is constantly kept moist, is supplied with numerous blood vessels, and upon which are spread the ultimate ramifications of the olfactory nerves. The relative magnitude of these nerves is much greater in carnivorous quadrupeds than in those which subsist on vegetable food. In quadrupeds as well as in man, these nerves are not collected into a single trunk in their course towards the brain, but compose a great number of filaments, which pass separately through minute perforations in a plate of bone, (called the *ethmoid bone*) before they en-



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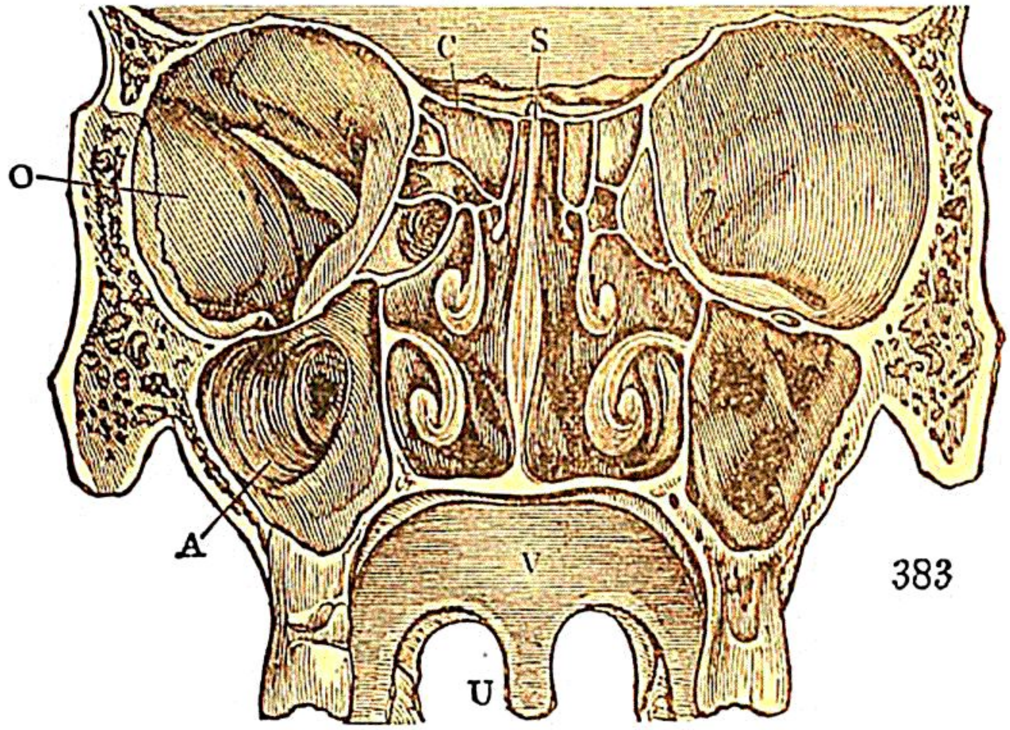
ter into the cavity of the skull, and join that part of the cerebral substance with which they are ultimately connected.

The surface of the membrane which receives the impressions from odorous effluvia, is considerably increased by several thin plates of bone, which project into the cavity of the nostrils, and are called the *turbinated bones*. These are delineated at T, T, in Fig. 382, as they appear in a vertical and longitudinal section of the cavity of the human nostril, where they are seen covered by the Schneiderian mem-

* It has been so named in honour of Schneider, the first anatomist who gave an accurate description of this membrane.

brane.* A transverse and vertical section of these parts is given in Fig. 383.† The turbinated bones are curiously folded, and often convoluted in a spiral form, with the evident design of obtaining as great an extent of surface as possible within the confined space of the nasal cavity. This tur-



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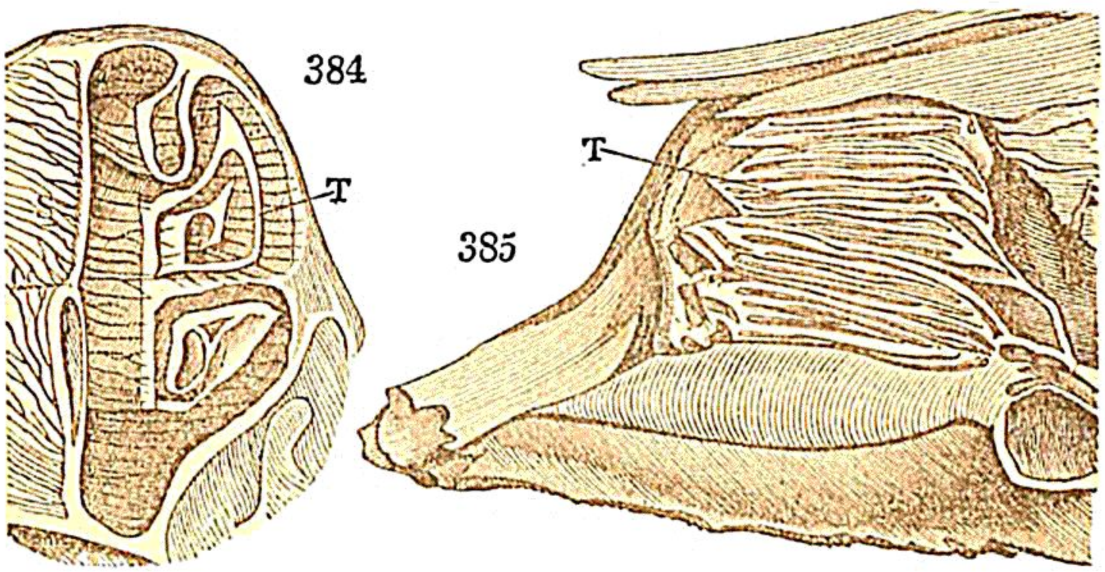
binated, or spiral shape, chiefly characterizes these bones among herbivorous quadrupeds: in the horse, for example, the turbinated bones are of a large diameter, and extend the whole length of the prolonged nostrils. Their structure is exceedingly intricate; for while they retain, externally, the general shape of an oblong spiral shell, they are pierced on all their internal sides with numerous perforations, through

* This figure shows the branches of the olfactory nerve (o,) passing through the thin *cribriform* plate of the ethmoid bone, and distributed over that membrane. Several of the cells, which open into the cavity, are also seen; such as the large sphenoidal sinus (s,) the frontal sinus (F,) and one of the ethmoidal cells (c.) N, is the nasal bone; P, the palate; and E, the mouth of the Eustachian tube, which leads to the ear.

† In this figure, s, is the septum, or partition of the nostrils, on each side of which are seen the sections of the turbinated bones projecting into the cavity; the ethmoid cells (c,) situated between the orbits (o;) and the *Antrum maxillare* (A,) which is another large cavity communicating with the nostrils.

which the membrane together with the finé branches of the nerves, pass freely from one side to the other. The cavities resulting from the convolutions are intersected by unperforated partitions of extraordinary tenuity, serving both to support the arches of bone, and to furnish a still greater surface for the extension of the olfactory membrane. In the Sheep, the Goat, and the Deer, the structùre is very similar to that just described; but the convolutions are double; with an intermediate partition, so as to resemble in its transverse section the capital of an Ionic column.* They are shown at T, Fig. 384, which exhibits the transverse section of the nostrils of a sheep.



In carnivorous quadrupeds the structure of these bones is still more intricate, and is calculated to afford a far more extensive surface for the distribution of the olfactory nerve. In the seal this conformation is most fully developed, and the bony plates are here not turbinated, but ramified, as

* In a species of Antelope described by Mr. Hodgson, cavities exist, situated immediately behind the ordinary nostrils, and communicating with them. These accessary nostrils, are conjectured to be useful to this exceedingly fleet animal by facilitating its breathing, while it is exerting its utmost speed; for the expansion of the nostrils opens also these posterior cavities, the sides of which, being elastic, remain dilated. Journal of the Asiatic Society, Feb. 1832, p. 59.

shown at T in Fig. 385. Eight or more principal branches arise from the main trunk; and each of these is afterwards divided and subdivided to an extreme degree of minuteness, so as to form in all, many hundred plates. The olfactory membrane, with all its nerves, is closely applied to every plate in this vast assemblage, as well as to the main trunk, and to the internal surface of the surrounding cavity: so that its extent cannot be less than 120 square inches in each nostril. An organ of such exquisite sensibility requires an extraordinary provision for securing it against injury, by the power of voluntarily excluding noxious vapours; and nature has supplied a mechanism for this express purpose, enabling the animal to close, at pleasure, the orifice of the nostril. The hog, which, in its natural state, subsists wholly on vegetable food, resembles herbivorous tribes in the external form and relative magnitude of the turbinated bones; but they are more simple in their structure, being formed of single, and slightly convoluted plates, without partitions or perforations. In this respect, they approach to the human structure, which is even less complicated, and indicates a greater affinity to vegetable than to animal feeders. Man, indeed, distinguishes more accurately vegetable odours than those proceeding from animal substances; while the reverse is observed with regard to quadrupeds whose habits are decidedly carnivorous. A dog, for instance, is regardless of the odour of a rose or violet; and, probably, as he derives from them no pleasure, is unable to discriminate the one from the other. Predacious animals, as Sir B. Harwood observes, require both larger olfactory nerves, and a more extensive surface for their distribution, than the vegetable eaters. The food of the latter is generally near at hand; and as they have occasion only to select the wholesome from the noxious plants, their olfactory organs are constructed for the purpose of arresting the effluvia of odorous substances immediately as they arise. The former are often under the necessity of discovering the lurking places of their prey at a considerable distance, and are therefore, more sensible to the weak impressions of particles widely diffused through the surrounding medium, or slightly adhering to those bodies, with which the object of their pursuit may have come into contact.

The olfactory bones of birds are constructed very much on the model of the spiral bones of herbivorous quadrupeds, and vary but little in the different species. Fig. 386 exhi-

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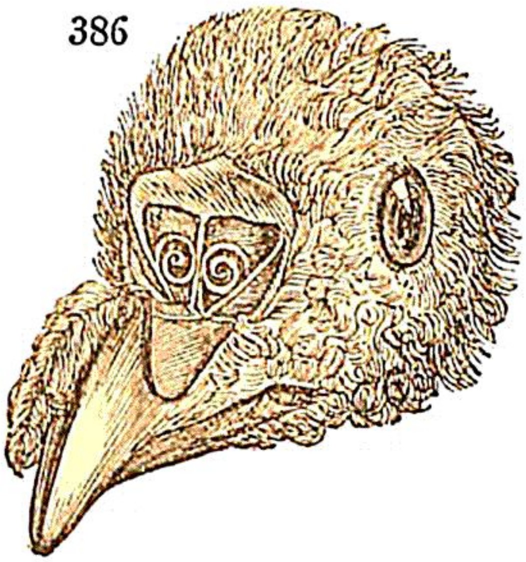

bits their appearance in the Turkey: but the size of the olfactory nerves of birds of prey greatly exceeds that of the same nerves in granivorous birds. In the latter, indeed, they are exceedingly small; and as the natural food of that tribe has but little odour, we find that they are easily deceived by any thing which bears a resemblance to it. Sir Busick Harwood relates that some poultry, which were usually fed with a mixture of barley meal and water, were found to have swallowed, by mistake, nearly the whole contents of a pot of white paint. Two of the fowls died, and two others became paralytic. The crops of the latter were opened, and considerably more than a pound of the poisonous composition taken from each; and the crops, either naturally, or from the sedative effects of the paint, appeared to have so little sensibility that, after the wounds were sewed up, both the fowls eventually recovered.

The olfactory nerves are conspicuous in the Duck, both from their size and mode of distribution. They are seen in Fig. 387, passing out through the orbit of the eye (O) in two large-branches, an upper one (U,) and a lower one (L,) the ramifications of which are spread over the mandibles,

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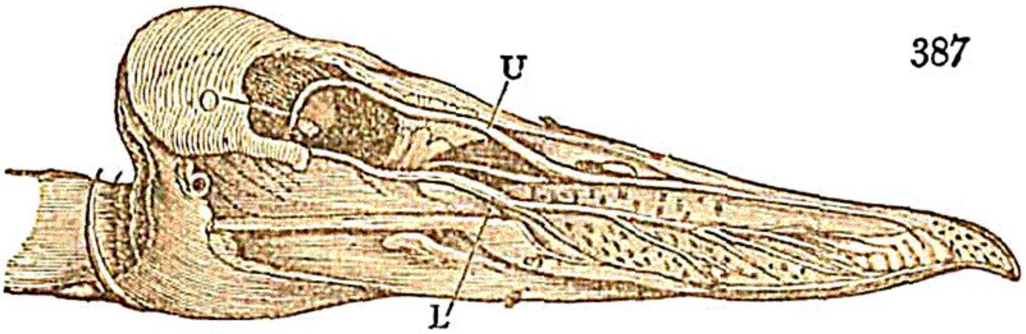

both within and without. For the protection of the highly sensible extremity of the beak against the injurious impressions of hard bodies, a horny process (P,) similar, both in form and office, to the human nail, is attached to it, and its edges guarded by a narrow border of the same horny material; these receive a first, and fainter impression, and admonish the animal of approaching danger; if none occur, the matter is then submitted to the immediate scrutiny of the nerves themselves, and is swallowed or rejected according to their indication.*

It has been generally asserted that Vultures, and other birds of prey, are gifted with a highly acute sense of smell; and that they can discover by means of it the carcass of a dead animal at great distances: but it appears to be now sufficiently established by the observations and experiments of Mr. Audubon, that these birds in reality possess the sense of smell in a degree very inferior to carnivorous quadrupeds; and that so far from guiding them to their prey from a distance, it affords them no indication of its presence, even when close at hand. The following experiments appear to be perfectly conclusive on this subject. Having procured the skin of a deer, Mr. Audubon stuffed it full of hay; and after the whole had become perfectly dry and hard, he placed it in the middle of an open field, laying it down on

* Such is the account given by Sir Busick Harwood, in his "System of Comparative Anatomy and Physiology," p. 26.

its back, in the attitude of a dead animal. In the course of a few minutes afterwards, he observed a vulture flying towards it, and alighting near it. Quite unsuspicious of the deception, the bird immediately proceeded to attack it, as usual, in the most vulnerable points. Failing in his object, he next, with much exertion, tore open the seams of the skin, where it had been stitched together, and appeared earnestly intent on getting at the flesh, which he expected to find within, and of the absence of which, not one of his senses was able to inform him. Finding that his efforts, which were long reiterated, led to no other result than the pulling out large quantities of hay, he at length, though with evident reluctance, gave up the attempt, and took flight in pursuit of other game to which he was led by the sight alone, and which he was not long in discovering and securing.

Another experiment, the converse of the first, was next tried. A large dead hog was concealed in a narrow and winding ravine, about twenty feet deeper than the surface of the earth around it, and filled with briers and high cane. This was done in the month of July, in a tropical climate, where putrefaction takes place with great rapidity. Yet, although many vultures were seen, from time to time, sailing in all directions over the spot where the putrid carcass was lying, covered only with twigs of cane, none ever discovered it; but in the mean while, several dogs had found their way to it, and had devoured large quantities of the flesh. In another set of experiments, it was found that young vultures, enclosed in a cage, never exhibited any tokens of their perceiving food, when it could not be seen by them, however near to them it was brought.*

It has been doubted whether fishes, and other aquatic animals, possess the sense of smell: in some of the whale tribe,

* Edinburgh New Journal of Science, ii. 172. The accuracy of these results, which had been contested by Mr. Waterton, is fully established by the recent observations and experiments of Mr. Bachman, which are detailed in Loudon's Magazine of Nat. Hist. vii. 167.

indeed, neither the organ of smell nor the olfactory nerves are found.* Some physiologists have gone the length of denying the capability of water to serve as the vehicle of odorous effluvia. But as water is known to contain a large quantity of air, which acts upon the organs of respiration, it is easy to conceive that it may also convey to the nostrils the peculiar agents which are calculated to excite perceptions of smell. Fishes are, in fact, observed to be attracted from great distances by the effluvia of substances thrown into the water; and they are well known to have a strong predilection for all highly odoriferous substances. Baits used by anglers are rendered more attractive by being impregnated with volatile oils, or other substances having a powerful scent, such as asafœtida, camphor, and musk. Mr. T. Bell† has discovered in the Crocodile and Alligator, a gland, which secretes an unctuous matter, of a strong, musky odour, situated beneath the lower jaw, on each side. The external orifice of this gland is a small slit, a little within the lower edge of the jaw; and the sac, or cavity containing the odoriferous substance, is surrounded by two delicate bands of muscular fibres, apparently provided for the purpose of first bringing the gland into a proper position, and then, by compressing it, discharging its contents. Mr. Bell conceives that the use of this secretion is to act as a bait for attracting fish towards the sides of the mouth, where they can be readily seized in the mode usual to the alligator, which is that of snapping sideways at the objects he aims at devouring.

The organs of smell in Fishes are situated in cavities, placed one on each side, in front of the head; they are merely blind sacs, having no communication with the mouth or throat, and, indeed, no other outlet but the external openings, which are generally two to each sac. The principal entrance is furnished with a valve, formed by a moveable membrane, appearing like a partition dividing each nostril

* Home; Lectures on Comparative Anatomy, i. 17.

† Phil. Trans. for 1827, p. 132.

into two cavities, and serving the purpose of preventing the introduction of any foreign body. The organ itself is situated behind this valve, and consists either of a membrane, curiously plaited into numerous semicircular folds, or of tufted or arborescent filaments. Fig. 388 shows this cavity

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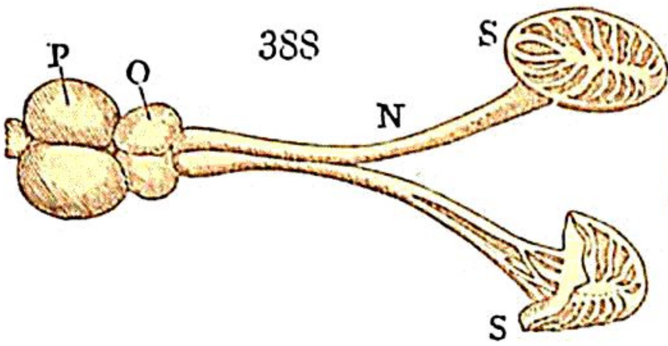

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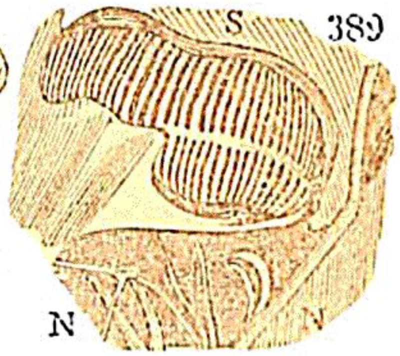


(s,) with its plaited membrane in the Perch; and Fig. 389, in the Skate; the laminæ in the former being radiated, and in the latter, foliated, or parallel to each other. On the surface of these organs, whatever be their shape, the olfactory nerves, (N.) arising from the anterior lobes (o) of the brain, are distributed; and the great size of these nerves would lead us to infer considerable acuteness in the sense which they supply. When the fish is swimming, their situation in front of the snout exposes them to the forcible impulse of the water which strikes against them. According to Geoffroy St. Hilaire, the water enters the cavity by the upper orifice, and escapes by the lower. Scarpa alleges that fishes exercise this sense by compressing the water against the membrane. On the other hand, it is contended by Duméril, that the perceptions communicated by this organ, being the result of the action of a liquid instead of a gas, should be classed under the head of taste rather than of smell. This seems, however, to be a mere verbal criticism, in making which it appears to have been forgotten that the impressions of odorous effluvia, even in animals breathing atmospheric air, always act upon the nerve through the intermedium of the fluid which lubricates the membrane of the nostril.

That the nasal cavities of fishes are rudimental forms of those of the mammalia, although they do not, as in the latter class, open into the respiratory organs, is shown by the curious transformation of the one into the other during the development of the tadpole, both of the frog and of the salamander. We have already seen that during the first periods of their existence, these animals are perfectly aquatic, breathing water by means of gills, and having all their organs formed on the model of the fish. Their nasal cavities are not employed for respiration at this early period, nor even for some time after they have begun to take in air, which they do by the mouth, swallowing it in small portions at a time, and afterwards throwing it out in bubbles by the same orifice. But when they quit the water, and become land animals with pulmonary respiration, the nostrils are the channels through which the air is received and expelled; and it is here also that the sense of smell continues to be exercised.

We know very little respecting the seat of the sense of smell in any of the invertebrated animals, though it is very evident that insects, in particular, enjoy this faculty in a very high degree. Analogy would suggest the spiracles as the most probable seat of this sense, being the entrances to the respiratory passages. This office has, however, been assigned by many to the antennæ; while other entomologists have supposed that the palpi are the real organs of smell.* Experiments on this subject are attended with great difficulty, and their results must generally be vague and inconclusive. Those which Mr. P. Huber made on bees, seem, however, to establish, with tolerable certainty, that the spiracles are insensible to strong odours, such as that of oil of turpentine, which is exceedingly offensive to all insects. It was only when a fine camel-hair pencil containing this pungent fluid was presented near the cavity of the mouth, above the insection of the proboscis, that any visible effect was produced upon the insect, which then gave decisive indications

* On the subject of this sense in insects, see Kirby and Spence's Introduction to Entomology, vol. iv. p. 249.

of strong aversion. Mr. Kirby has discovered in the anterior part of the nose of the *Necrophorus vespillo*, or burying beetle, which is an insect remarkable for the acuteness of its smell, a pair of circular pulpy cushions, covered with a membrane, beautifully marked with fine transverse furrows. These he considers as the organs of smell; and he has found similar structures in several other insects.*

No distinct organs of smell have been discovered in any of the Mollusca;† but as there is evidence that some of the animals belonging to that class possess this sense, it has been conjectured that it resides either in the whole mucous surface of the mantle, or in the respiratory organs. Swammerdam observed, long ago, that snails are evidently affected by odours; and the cuttle-fish is said to show a decided aversion to strongly-scented plants.

* Kirby and Spence's Introduction to Entomology, vol. iii. 481; and iv. 254.

† A group of laminæ, closely resembling the olfactory organs of Fishes, has been lately observed by Mr. Owen.

CHAPTER V.

HEARING.

§ 1. *Acoustic Principles.*

The knowledge acquired by animals of the presence and movements of distant objects is derived almost wholly from the senses of hearing and of sight; and the apparatus, necessary for the exercise of these senses, being more elaborate and refined than any of the organs we have yet examined, exhibit still more irrefragable evidence of those profound designs, and that infinite intelligence, which have guided the construction of every part of the animal frame.

Sound results from certain tremulous or vibratory motions of the particles of an elastic medium, such as air or water, excited by any sudden impulse or concussion given to those particles by the movements of the sounding body. These sonorous vibrations are transmitted with great velocity through those fluids, till they strike upon the external ear; and, then, after being concentrated in the internal passages of the organ, they are made to act on the filaments of a particular nerve called the *acoustic*, or *auditory* nerve, of which the structure is adapted to receive these peculiar impressions, and to communicate them to the brain, where they produce changes, which are immediately followed by the sensation of sound. Sound cannot traverse a void space, as light does; but always requires a ponderable material vehicle for its transmission; and, accordingly, a bell suspended in the vacuum of an air-pump, gives, when struck, no audible sound, although its parts are visibly thrown into the usual vibratory motions. In proportion as air is admitted into the receiver, the sound becomes more and more distinct; and if, on the other hand, the air be condensed, the sound is louder than when the bell is surrounded by air of the ordinary density.*

The impulses given by the sounding body to the contiguous particles of the elastic medium, are propagated in every direction, from particle to particle, each, in its turn, striking against the next, and communicating to it the whole of its own motion, which is destroyed by the reaction of the particle against which it strikes. Hence, after moving a certain definite distance, a distance, indeed, which is incalculably small, each particle returns back to its former situation, and is again ready to receive a second impulse. Each particle, being elastic within a certain range,† suffers a momentary compression, and immediately afterwards resumes its former shape: the next particle is, in the mean time, impelled, and undergoes the same succession of changes; and so on, throughout the whole series of particles. Thus, the sonorous undulations have an analogy to waves, which spread in circles on the surface of water, around any body, which, by its motion, ruffles that surface; only that, instead of merely extending in a horizontal plane, as waves do, the sonorous undulations spread out in all directions, forming, not circles in one plane, but spherical shells; and, whatever be the intensity of the sounds, the velocity with which the undulations advance is uniform, as long as they continue in a medium of uniform density. This velocity in air, is, on an average, about 1100 feet in a second, or twelve and a half

* These facts were first ascertained by Dr. Hauksbee. See Philosophical Transactions for 1705, vol. xxiv. p. 1902, 1904.

† The particles of water are as elastic, within a limited distance, as those of the most solid body, although, in consequence of their imperfect cohesion, or, rather, their perfect mobility in all directions, this property cannot be so easily recognised in the masses of fluids, as in solids.

miles in a minute: it is greater in dense, and smaller in rarefied air; being, in the same medium, exactly proportioned to the elasticity of that medium.

Water is the medium of sound to aquatic animals, as the air is to terrestrial animals. Sounds are, indeed, conveyed more quickly, and to greater distances, in water than in air, on account of the greater elasticity of the constituent particles of water, within the minute distance required for their action in propagating sound. Stones, struck together under water, are heard at great distances by a person whose head is under water. Franklin found, by experiment, that sound, after travelling above a mile through water, loses but little of its intensity. According to Chladni, the velocity of sound in water is about 4900 feet in a second, or between four and five times greater than it is in air.

Solid bodies, especially such as are hard and elastic, and of uniform substance, are also excellent conductors of sound. Of this we may easily convince ourselves by applying the ear to the end of a log of wood, or a long iron rod, in which situation we shall hear very distinctly the smallest scratch made with a pin at the other end: a sound, which, had it passed through the air only, would not have been heard at all. In like manner, a poker suspended by two strings, the ends of which are applied to the two ears, communicates to the organ, when struck, vibrations which would never have been heard under ordinary circumstances. It is said that the hunters in North America, when desirous of hearing the sounds of distant footsteps, which would be quite inaudible in any other way, apply their ears close to the earth, and then readily distinguish them. Ice is known to convey sounds, even better than water: for if cannon be fired from a distant fort, where a frozen river intervenes, each flash of light is followed by two distinct reports, the first being conveyed by the ice, and the second by the air. In like manner, if the upper part of the wall of a high building be struck with a hammer, a person standing close to it on the ground, will hear two sounds after each blow, the first descending through the wall, and the second through the air.

As sounds are weakened by diffusion over a larger sphere of particles, so they are capable of having their intensity increased by concentration into a smaller space; an effect which may be produced by their being reflected from the solid walls of cavities, shaped so as to bring the undulations to unite into a focus; it is on this principle that the ear-trumpet, for assisting persons dull of hearing, is constructed; and the same effect sometimes takes place in echoes, which occasionally reflect a sound of greater loudness than the original sound which was directed towards them.

If the impulses given to the nerves of the ear be repeated at equal intervals of time, provided these intervals be very small, the impressions become so blended together as not to be distinguishable from one another, and the sensation of a uniform continued sound, or *musical note*, is excited in the mind. If the intervals between the vibrations be long, the note is *grave;* if short, that is, if the number of vibrations in a given time be great, the note is, in the same proportion, *acute.* The former is called a *low*, the latter a *high note;* designations which were, perhaps, originally derived from the visible motions of the throat of a person who is singing these different notes; for, independently of this circumstance, the terms of high and low are quite arbitrary; and it is well known that they were applied by the ancients in a sense exactly the reverse of that in which me now use them.

The different degrees of tension given to the cord or wire of a stringed musical instrument, as well as its different lengths, determine the frequency of its vibrations; a greater tension, or a shorter length, rendering them more frequent, and consequently producing a higher note; and on the contrary, the note is rendered more grave by either lessening the tension, or lengthening the cord or wire. In a wind instrument, the tone depends chiefly upon the length of the tube producing the sound.

There are, therefore, two qualities in sound recognisable by the ear, namely, loudness, or *intensity*, and quality, or *tone;* the former depending on the force of the vibrations; the latter, on their frequency. These acoustic principles are to be borne in mind in studying the comparative physiology of hearing; and since the functions of the different parts of the organ of this sense are, as yet, but imperfectly understood, I shall, in treating of this subject, deviate from the plan I have hitherto followed, and premise an account of the structure of the ear in its most perfectly developed state, as it appears to be in Man.

§ 2. *Physiology of Hearing in Man.*

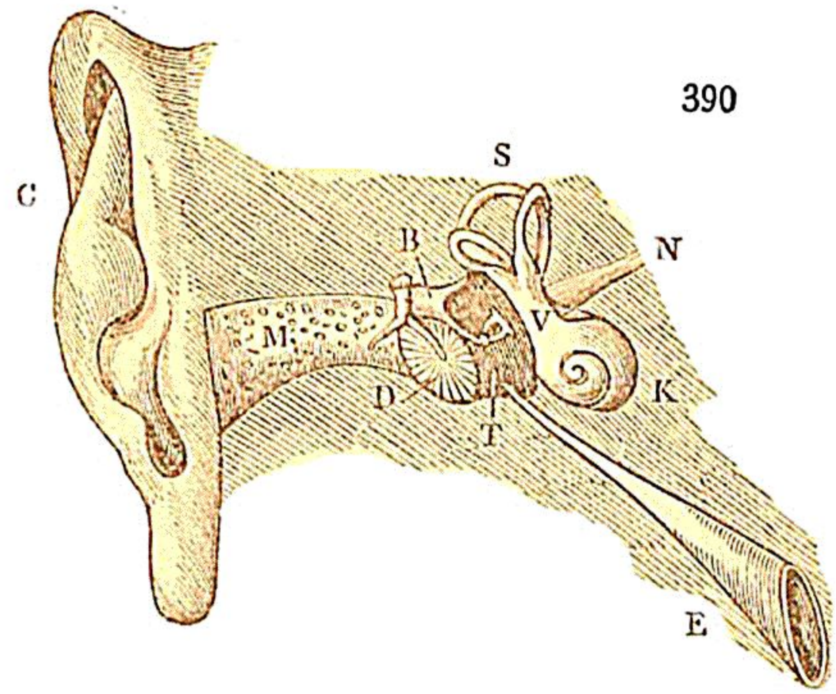
That part of the organ of hearing, which, above all others is essential to the performance of this function, is the acoustic nerve, of which the fibres are expanded, and spread over the surface of a fine membrane, placed in a situation adapted to receive the full impression of the sonorous undulations which are conveyed to them. This membrane, then, with its nervous filaments, may be regarded as the immediate organ of the sense; all the other parts constituting merely an accessory apparatus, designed to collect and to condense the vibrations of the surrounding medium, and to direct their concentrated action on the auditory membrane.

I have endeavoured, in Fig. 390, to exhibit, in one view, the principal parts of this complicated organ, as they exist in man, in their relative situations, and of their natural size; thereby affording a scale by which the real dimensions of those portions, which I shall afterwards have occasion to explain by magnified representations, may be properly appreciated.*

The *concha*, or external ear (c,) is formed of an elastic plate of cartilage, covered by integument, and presenting va-

* In this and all the following figures, the parts of the right ear are shown, and similar parts are always indicated by the same letters.

rious elevations and depressions, which form a series of parabolic curves, apparently for the purpose of collecting the sonorous undulations of the air, and of directing them into a funnel-shaped canal (M,) termed the *meatus auditorius;*



which leads to the internal ear. This canal is composed partly of cartilage, and partly of bone; and the integument lining it is furnished with numerous small glands, which supply a thick oily fluid, of an acrid quality, apparently designed to prevent the intrusion of insects: the passage is also guarded by hairs, which appear intended for a similar purpose.

The meatus is closed at the bottom by a membrane (D,) which is stretched across it like the skin of a drum, and has been termed, from this resemblance, the *membrane of the tympanum*, or the *ear-drum.** It performs, indeed, an office corresponding to its name; for the sonorous undulations of the air, which have been collected, and directed inwards by the grooves of the concha, strike upon the ear-drum, and throw it into a similar state of vibration. The ear-drum is

* The inner surface of the ear-drum is shown in this figure, the cavity of the tympanum, which is behind it, being laid open.

composed of an external membrane, derived from the cuticle which lines the meatus; an internal layer, which is continuous with that of the cavity beyond it; and a middle layer, which consists of radiating muscular fibres, proceeding from the circumference towards the centre, where they are inserted into the extremity of a minute bony process (H,) presently to be described.* This muscular structure appears designed to vary the degree of tension of the ear-drum, and thus adapt the rate of its vibrations to those communicated to it by the air. There is, also, a slender muscle, situated internally, which, by acting on this delicate process of bone, as on a lever, puts the whole membrane on the stretch, and enables its radiating fibres to effect the nicer adjustments required for tuning, as it may be called, this part of the organ.†

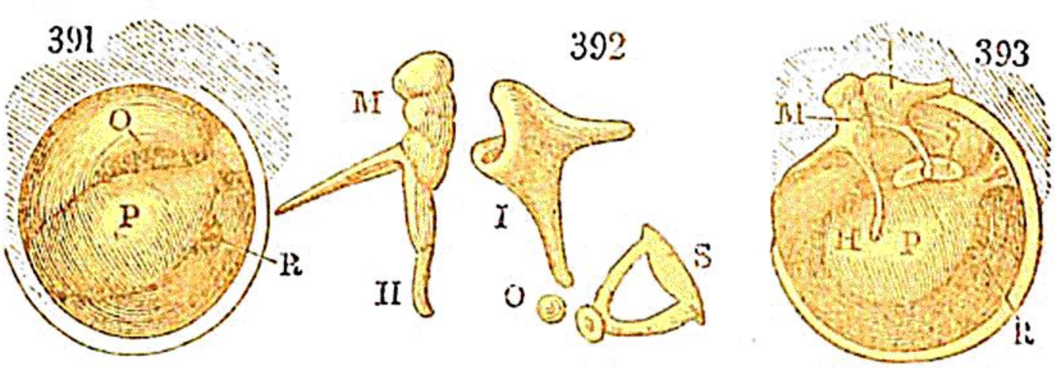
Immediately behind the membrane of the ear-drum, there is a hollow space (T,) called the *cavity of the tympanum*, of an irregular shape, scooped out of the most solid part of the temporal bone, which is here of great density and hardness. This cavity is always filled with air; but it would obviously defeat the purpose of the organ if the air were confined in this space; because unless it were allowed occasionally to expand or contract, it could not long remain in equilibrium with the pressure exerted by the atmosphere on the external surface of the ear-drum; a pressure which, as is well known, is subject to great variations, indicated by the rise and fall of the barometer. These variations would expose the membrane of the ear-drum to great inequalities of pressure at its outer and inner surfaces, and endanger its being forced, according to the state of the weather, either outwards or inwards, which would completely interfere with the delicacy of its vibrations. Nature has guarded against

* In many quadrupeds their insertion into this process is at some distance from the centre of the membrane. These muscular fibres are delineated in Fig. 45, vol. i. p. 105.

† Home, Lectures, &c., iii. 268.

these evils by establishing a passage of communication between the tympanum and the external air, by means of a tube (E,) termed the *Eustachian tube*, which begins by a small orifice from the inner side of the cavity of the tympanum, and opens by a wide mouth at the back of the nostrils.* This tube performs the same office in the ear, as the hole which it is found necessary to make in the side of a drum, for the purpose of opening a communication with the external air; a communication which is as necessary for the functions of the ear, as it is for the proper sounding of the drum. We find accordingly that a degree of deafness is induced whenever the Eustachian tube is obstructed, which may happen either from the swelling of the membrane lining it, during a cold, or from the accumulation of secretion in the passage. It is also occasionally useful as a channel through which sounds may gain admittance to the internal ear; and it is perhaps for this reason that we instinctively open the mouth when we are intent on hearing a very faint or distant sound.

On the side of the cavity of the tympanum, which is opposite to the opening of the Eustachian tube, is situated the beginning of another passage, leading into numerous cells, contained in the *mastoid process* of the temporal bone, and therefore termed the *mastoid cells:* these cells are likewise



filled with air. The innermost side of the same cavity, that

* This opening is seen at L, in Fig. 382, p. 283, representing a vertical and longitudinal section of the right nostril.

is, the side opposite to the ear-drum, and which is shown in Fig. 391, is occupied by a rounded eminence (P,) of a triangular shape, termed the *promontory;* on each side of which there is an opening in the bone, closed, however, by the membrane lining the whole internal surface of the cavity. The opening (O,) which is situated at the upper edge of the promontory is called the *fenestra ovalis*, or oval window; and that near the under edge (R,) is the *fenestra rotunda*, or round window.

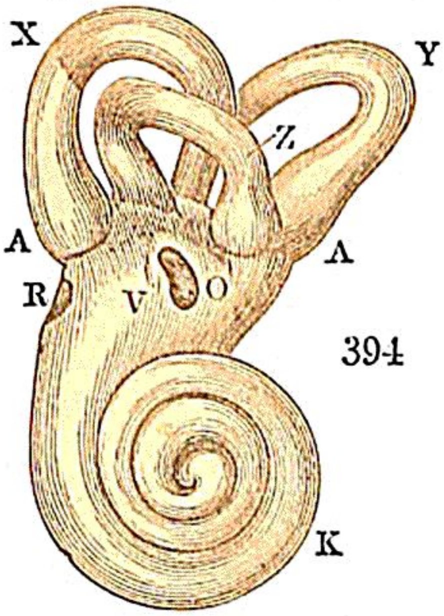
Connected with the membrane of the ear-drum, at one end, and with the fenestra ovalis at the other, there extends a chain of very minute moveable bones, seen at (B,) in Fig. 390; but more distinctly at M, I, S, in Fig. 393, which is drawn on a somewhat larger scale, and in which, as before, P is the promontory; and R the fenestra rotunda. These bones, which may be called the *tympanic ossicula*, are four in number, and are represented, enlarged to twice the natural size, in Fig. 392. The names they have received are more descriptive of their shape than of their office. The first is the *malleus*, or hammer (M;) and its long handle (H) is affixed to the centre of the ear drum: the second is the *incus*, or anvil (I;) the third, which is the smallest in the body, being about the size of a millet seed, is the *orbicular bone* (O;)* and the last is the *stapes*, or stirrup (S,) the base of which is applied to the membrane of the fenestra ovalis. These bones are regularly articulated together, with all the ordinary apparatus of joints, and are moved by small muscles provided for that purpose. Their office is apparently to transmit the vibrations of the ear-drum to the membrane of the fenestra ovalis, and probably, at the same time, to increase their force.

The more internal parts of the ear compose what is de-

* Blumenbach, and other anatomists, consider this as not being a separate bone, but only a process of the *incus;* a view of the subject which is supported by the observations of Mr. Shrapnell, detailed in the Medical Gazette, xii. 172.

http://www.geology.19thcenturyscience.org/books/Bridgewater-Treatises/index.html

signated, from the intricacy of its winding passages, the *labyrinth*.



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It is seen at (S V K) in Fig. 390, in connexion with the tympanum; but in Fig. 394, it is represented, on a very large scale, detached from every other part, and separated from the solid bone in which it lies imbedded. It consists of a middle portion, termed the *vestibule* (V,) from which, on its upper and posterior side, proceed the three tubes (X, Y, Z,) called, from their shape, the *semicircular canals;* while to the lower anterior side of the vestibule there is attached a spiral canal, resembling in appearance the shell of a snail, and on that account denominated the *Cochlea* (K.) All these bony cavities are lined with a very delicate membrane, or *periosteum,* and are filled with a transparent watery, or thin gelatinous fluid, which is termed by Breschet, the *perilymph.**

Within the cavity of the *osseous labyrinth,* now described, are contained membranes having nearly the shape of the vestibule and semicircular canals, but not extending into the cochlea. These membranes, which compose what has been termed, for the sake of distinction, the *membranous labyrinth,* form one continuous, but closed sac, containing a fluid,† perfectly similar in appearance to the perilymph, which surrounds it on the outer side, and intervenes between it and the sides of the osseous labyrinth, preventing any contact with those sides. In Fig. 395, which is on a still larger scale than the preceding figure, the osseous labyrinth is laid open, so as to show the part it encloses, and

* Annales des Sciences Naturelles, xxix. 97. It has also been called the *Aqua labyrinthi,* and the *fluid of Cotunnius,* from the name of the Anatomist who first distinctly described it.

† De Blainville has termed this fluid "la vitrine auditive," from its supposed analogy with the vitreous humour of the eye.

more especially the membranous labyrinth, floating in the perilymph (P.) The form of this latter part is still more distinctly seen, in Fig. 396, where it is represented in a position exactly corresponding to the former figure, but wholly detached from the bony labyrinth, and connected only with the nervous filaments which are proceeding to be distributed to its different parts.

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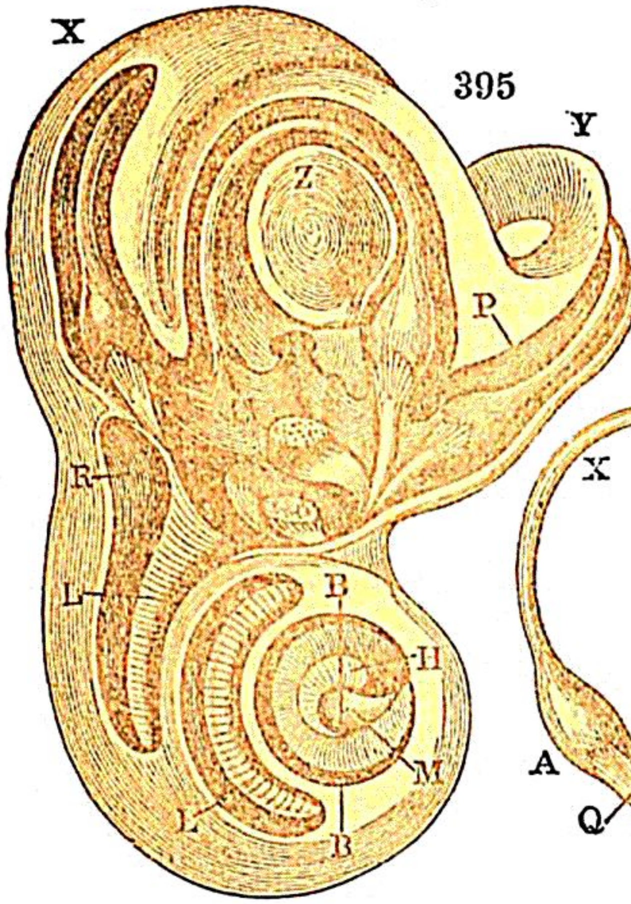

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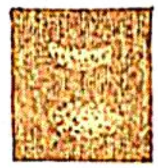

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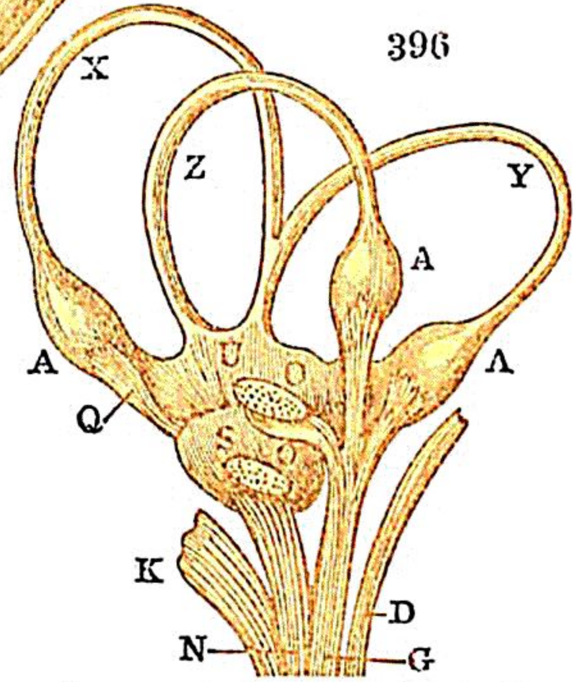


A simple inspection of these figures, in both of which the corresponding parts are marked by the same letters, will show at once the form and the connexions of the three semicircular canals, (X, Y, Z,) each of which present, at their origin from the vestibule, a considerable dilatation, termed an *ampulla* (A, A, A,) while, at their other extremities, where they terminate in the vestibule, there is no enlargement of their diameter; and it will also be seen that two of these canals (X and Y) unite into one before their termination. The same description applies in all respects both to the osseous and to the membranous canals contained within them; the space (P) which intervenes between the two, being filled with the perilymph. But the form of the membranous vestibule demands more particular notice, as it is not so exact an imitation of that of the osseous cavity; being composed of two distinct sacs, opening into each other: one of these (U) is termed the *utricle*;* and the other (S,) the *sacculus*. Each sac contains in its interior a small mass of white calcareous matter, (O, O,) resembling powdered chalk, which seems to be suspended in the fluid contained in the sacs by the intermedium of a number of nervous filaments proceeding from the acoustic nerves (U and N,) as seen in Fig. 396. From the universal presence of these cretaceous substances in the labyrinth of all the mammalia, and from their much greater size and hardness in aquatic animals, there can be little doubt that they perform some office of great importance in the physiology of hearing.† Their size and appearance in the Dog is shown in Fig. 397; and in the Hare, in Fig. 398.

The Cochlea, again, is an exceedingly curious structure, being formed of the spiral convolutions of a double tube, or rather of one tube, separated into two compartments by a partition (L,) called the *lamina spiralis*, which extends its whole length, except at the very apex of the cone, where it suddenly terminates in a curved point, or hook (H,) leaving an aperture by which the two portions of the tube communicate together. In Fig. 395, a bristle (B, B) is passed through this aperture. The central pillar, round which these tubes take two and a half circular turns, is termed the *modiolus*. Its apex is seen at (M.) One of these passages is distinguished by the name of the *vestibular tube*,‡ in consequence

* Scarpa and Weber term it the *sinus* or *alveus utriculosus*; it is called by others the *sacculus vestibuli*. Breschet gives it the name of *le sinus médian*. See the Memoir already quoted, p. 98.

† These cretaceous bodies are termed by Breschet *otolithes*, and *otoconies*, according as they are of a hard or soft consistence. Ibid. p. 99.

‡ *Scala vestibuli*.

of its arising from the cavity of the vestibule; and the other by that of the tympanic tube,* because it begins from the inner side of the membrane which closes the fenestra rotunda, and forms the only separation between the interior of that tube, and the cavity of the tympanum. The trunk of the auditory nerve occupies a hollow space immediately behind the ventricle, and its branches pass through minute holes in the bony plate which forms the wall of that cavity, being finally expanded on the different parts of the membranous labyrinth.†

Great uncertainty prevails with regard to the real functions performed by the several parts of this very complex apparatus. It is most probable, however, that the sonorous vibrations of the air which reach the external ear, are directed down the meatus, and striking against the ear-drum which closes the passage, throw that membrane into vibrations of the same frequency; to which the action of its muscles, which appear intended to regulate its tension, may also contribute. The vibrations of the ear-drum, no doubt, excite corresponding motions in the air contained in the cavity of the tympanum; which, again, communicates them to the membrane of the fenestra rotunda; while, on the other hand, the membrane closing the fenestra ovalis, receives similar impressions from the stapes, conveyed through the chain of tympanic ossicula, which appear to serve as solid conductors of the same vibrations. Thus, the perilymph, or fluid contained in the labyrinth, is affected by each external sound, both through the medium of the air in the tympanum, and by means of the ossicula: the undulations thus excited pro-

* *Scala tympani.*

† In Fig. 396, the anterior trunk of the auditory nerve is seen (at G) distributing branches to the ampullæ (A, A,) the utricle (U,) and the calcareous body it contains; while the posterior trunk (N) divides into a branch, which supplies the sacculus (S) and its calcareous body (O) and a second branch (K) which is distributed over the cochlea. (D) is the nerve called the *portio dura*, which merely accompanies the auditory nerve, but has no relation to the sense of hearing. In Fig. 390, the auditory nerve (N) is seen entering at the back of the vestibule.

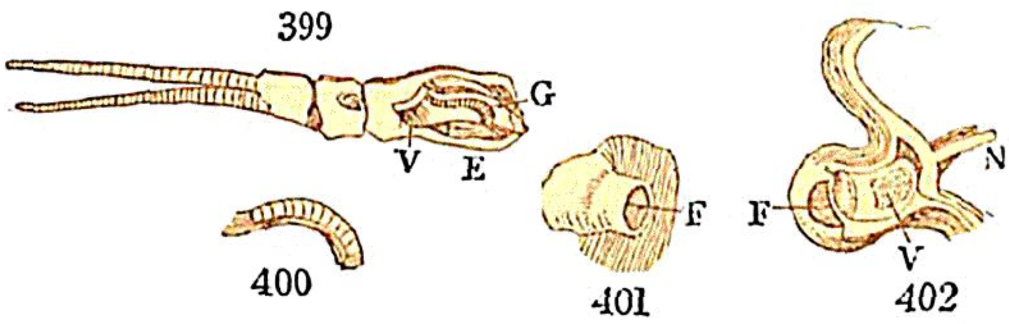
duce impressions on the extremities of the nervous filaments, which are spread over the membranous labyrinth; and these impressions being conveyed to the brain, are immediately followed by the sensation of sound.

With regard to the purposes which are answered by the winding passages of the semicircular canals, and cochlea, hardly any plausible conjecture has been offered; yet no doubt can be entertained that the uses of all these parts are of considerable importance, both as to delicacy and correctness of hearing. There is an obvious correspondence between the positions of the three semicircular canals, (two of which are vertical, and one horizontal, and of which the planes are reciprocally perpendicular to one another,) and the three dimensions by which the geometrical relations of space are estimated; and it might hence be conjectured that the object of this arrangement is to allow of the transmission of vibrations of every kind, in whatever direction they may arrive. It is not an improbable supposition that the return into the vestibule, of undulations which have passed through these canals, has the effect of at once putting a stop to all farther motion of the fluid, and preventing the continuance of the impression which has been already made on the nerves. The same use may be assigned to the double spiral convolutions of the tubes of the cochlea; for the undulations of the fluid in the tympanic tube, received from the membrane of the fenestra rotunda, will meet those proceeding along the vestibular tube, derived from the membrane of the fenestra ovalis, and like two opposing waves, will tend to destroy one another. Thus each external sound will produce but a single momentary impression; the prolongation of the undulations of the fluid of the labyrinth being prevented by their mutual collision and neutralization.*

* The preliminary steps in the process above described are not absolutely essential to hearing, for many instances have occurred in which the power of hearing has been perfectly retained after the membrane of the ear-drum, and also the ossicula had been destroyed by disease. A small aperture in the membrane does not interfere with its power of vibration; but if the whole

§ 3. *Comparative Physiology of Hearing.*

The structure of the organs of hearing in the lower animals presents a regular gradation from the simple vestibule, with its membranous sac, supplied with nervous filaments, which may be regarded as the only essential part of this organ, through the successive additions of semicircular canals, fenestra ovalis, tympanic cavity, ossicula, ear-drum, meatus auditorius, cochlea, and concha, till we arrive at the combination of all these parts in the higher orders of the Mammalia. The simpler forms are generally met with in aquatic animals, probably because the sonorous undulations of water are communicated more readily, and with greater force, than those of air, and require no accessory apparatus for their concentration. The lobster, for instance, has a vestibular cavity (seen at v, in Fig. 399,) containing a membranous sac, with a striated groove (G,)* and receiving the filaments of the auditory nerve. This vestibule is protected by the shell on all sides, except at one part, where it is closed only by a membrane (E,) which may therefore be considered as corresponding to the fenestra ovalis. The outer side of this membrane in the *Astacus fluviatilis*, or cray-fish, is seen at F in Fig. 401; while Fig. 402, shows an



ear-drum be destroyed, and the ossicula lost, an almost total deafness generally ensues. After a time, however, the hearing may be in a great measure recovered, with an undiminished power of distinguishing musical tones. See two papers by Sir Astley Cooper, in the Phil. Trans. for 1800, p. 151; and for 1801, p. 437.

* This groove is represented magnified in Fig. 400.

interior view of the same membrane (F,) with the vestibule (V) laid open, and the auditory nerve (N) passing through the shell to be distributed on the sacculus.

It appears from a variety of observations that Insects, both in their larva and their perfect state, possess the faculty of hearing; but no certain knowledge has been obtained of the parts which exercise this sense. The prevailing opinion among entomologists is that it resides in some part of the antennæ; organs, which are supposed to have a peculiar sensibility to aerial undulations. This hypothesis is founded principally on the analogy of the crustacea, whose antennæ contain the vestibular cavity already described; but on the other hand it is opposed by the fact that Spiders, which hear very acutely, have no antennæ, and it is also reported that insects, when deprived of their antennæ, still retain the power of hearing.*

None of the Mollusca appear to possess, even in the smallest degree, the sense of hearing, if we except the highly organized Cephalopoda; for in them we find, at the lower part of the cartilaginous ring, which has been supposed to exhibit the first rudiment of a cranium, a tubercle, containing in its interior two membranous vesicles, contiguous to each other, and surrounded by a fluid. They evidently correspond to the vestibular sacs, and contain each a small calcareous body, suspended from the vesicles by slender nervous filaments, like the clapper of a bell, and probably performing an office analogous to that instrument; for, being thrown into a tremulous motion by every undulation of the surrounding fluid, they will strike against the membrane, and communicate similar and still stronger impulses to the nerves by which they are suspended, thus increasing the impression made on those nerves. The mechanical effect of an apparatus of this kind is shown by the simple experiment,

* Comparetti has described structures in a great number of insects, which he imagined were organs of hearing; but his observations have not been confirmed by subsequent inquirers, and their accuracy is therefore doubtful. See De Blainville "De l'Organisation des Animaux," i. 565.

mentioned by Camper, of enclosing a marble in a bladder full of water, and held in the hand; when the slightest shaking of the bladder will be found instantly to communicate motion to the marble, the reaction of which on the bladder gives an unexpected concussion to the hand.

The ear of Fishes contains, in addition to the vestibule, the three semicircular canals, which are, in general, greatly developed.* *An enlarged view of the membranous labyrinth* of the *Lophius piscatorius*, is given in Fig. 403, showing the form and complication of its parts, which are represented of twice the natural size. X, Y, Z, are the semicircular canals, with their respective ampullæ (A, A, A.) M is the *Sinus medianus*, or principal vestibular sac, with its anterior expansion, termed the *Utricle* (U.) The *Sacculus* (S) has, in like manner, a posterior appendage (C) termed the *Cysticule*. The hard calcareous bodies (O, O, O) are three in number; and the branches of nerves (I, I, I) by which they are suspended in the fluid contained in the membranes, are seen passing into them; while the ampullæ are supplied by other branches (N, N, N.) In all the osseous fishes, the

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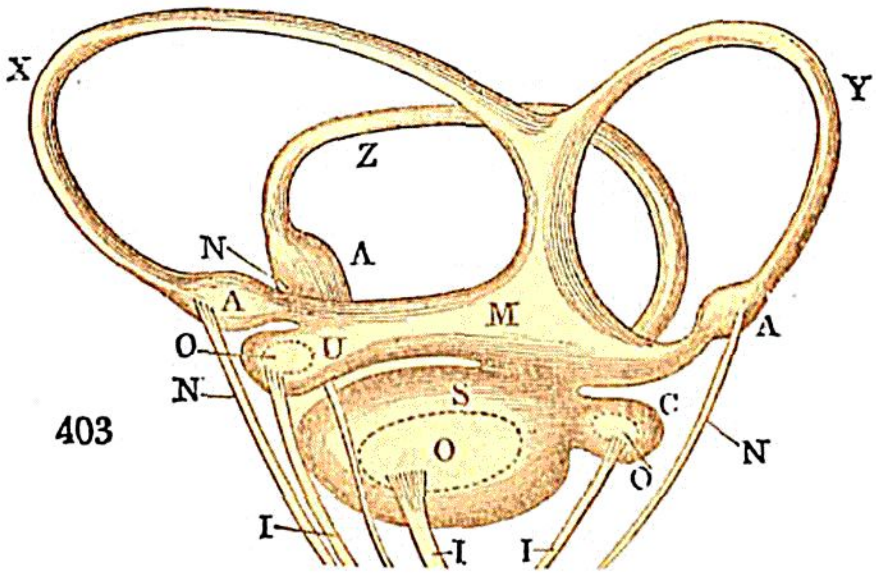
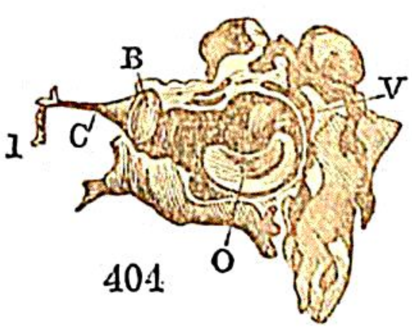


labyrinth *is not* enclosed in the bones of the cranium, but projects into its cavity; but in the larger cartilaginous fishes,

* In the lamprey, these canals exist only in a rudimental state, appearing as folds of the membrane of the vestibule; and there are also no cretaceous bodies in the vestibular sac.

as the ray and shark tribes, it is surrounded by solid bone, and is not visible within the cranium. In these latter fishes, we first meet with a rudiment of the meatus, in a passage extending from the inner side of the vestibule, to the upper and back part of the skull, where it is closed by a membrane, which is covered by the skin.

Aquatic reptiles have ears constructed nearly on the same plan as those of fishes: thus, the Triton or Newt has a vestibule containing only one cretaceous body, and three semicircular canals, unprotected by any surrounding bone. In the Frog, however, we first perceive the addition of a distinct cavity, closed by a membrane, which is on a level with the integuments, on each side of the head. From this cavity, which corresponds to that of the tympanum, there proceeds a Eustachian tube; and within it, extending from the external membrane, which must here be regarded as an ear-drum, to the membrane of the vestibule, or fenestra ovalis, is found a bone, shaped like a trumpet, and termed the *Columella*. This bone is seen at c in Fig. 404, attached



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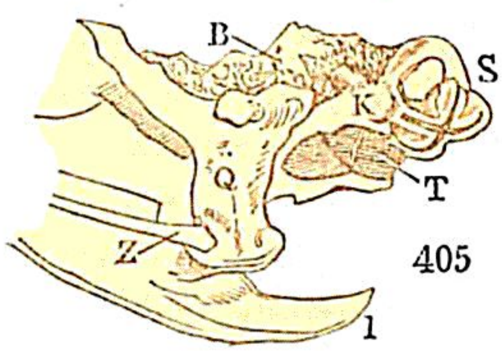

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by its base (B) to the fenestra ovalis of the vestibule (V,) which contains the cretaceous body (O.) There is also a small bone (I) attached in front to the columella. In the Chelonia, the structure of the ear is essentially the same as in the Frog, but the tympanum and columella are of greater length. In the saurian reptiles the cavity of the tympanum is still more capacious, and the ear-drum very distinctly marked, and these animals possess great delicacy of hearing. The labyrinth of the Crocodile is enclosed in bone, and contains three calcareous bodies: it presents also an appendage which has been regarded as the earliest rudiment of a cochlea; and there are two folds of the skin, resembling eye-lids, at the external orifice of the organ, which appear like the first step towards the development of an external ear.

The structure of the ear in the Crocodile is but an approximation to that which we find prevailing in Birds, where the organ is of large size compared with that of the head. The rudimental cochlea, as seen at K in Fig. 405, which represents these organs in the Turkey, is of large size, and slightly curved. In the cavity of the tympanum (T) is seen the columella, which extends to the fenestra ovalis; and beyond it, the semicircular canals (S,) the bony cells (B) which communicate with the tympanum, the os quadratum (Q,) the zygomatic process (Z,) and the lower jaw (J.) The ear-drum is now no longer met with at the surface, but lies concealed at the bottom of a short meatus, the orifice of which is surrounded with feathers arranged so as to serve as a kind of imperfect concha, or external ear.

In Owls these feathers are a prominent and characteristic feature; and in these birds there is, besides, a membranous flap, acting as a valve to guard the passage.

The chief peculiarity observable in the internal ears of Mammalia is the great development of the cochlea, the tubes of which are convoluted, turning in a spiral, and assuming the figure of a turbinated shell. From an extensive comparison of the relative size of the cochlea in different tribes of quadrupeds, it has been inferred that it bears a tolerably constant proportion to the degree of acuteness of hearing, and that, consequently, it contributes essentially to the perfection of that faculty: bats, for instance, which are known to possess exquisite delicacy of hearing, have a cochlea of extraordinary size, compared with the other parts of the ear. The tympanic ossicula are completely developed only in the Mammalia.* It is also in this class alone that

* These tympanic ossicula are regarded by Geoffroy St. Hilaire as corresponding to the opercular bones of fishes, where, according to his theory, they have attained their highest degree of development.

we meet with a concha, or external ear, distinctly marked; and the utility of this part, in catching and collecting the sonorous undulations of the air, may be inferred from the circumstance, that a large and very moveable concha is generally attended with great acuteness of hearing. This is more particularly the case with feeble and timid quadrupeds, as the hare and rabbit, which are ever on the watch to catch the most distant sounds of danger, and whose ears are turned backwards, or in the direction of their pursuers; while, on the contrary, the ears of predaceous animals are directed forwards, that is, towards the objects of their pursuit. This difference in direction is not confined to the external ear, but is observable also in the bony passage leading to the tympanum.

The Cetacea, being strictly inhabitants of the water, have no external ear; and the passage leading to the tympanum is a narrow and winding tube, formed of cartilage instead of bone, and having a very small external aperture. In the Dolphin tribe the orifice will barely admit the entrance of a pin; it is also exceedingly small in the *Dugong;* these structures being evidently intended for preventing the entrance of any quantity of water.* It is apparently with the same design that in the *Seal* the passage makes a circular turn; and that, in the *Ornithorhyncus paradoxus,* it winds round the temporal bone, and has its external orifice at a great distance from the vestibule. The internal parts of the organ of hearing in the Whale, and other cetacea, are enclosed in a bone of extraordinary hardness, which, instead of forming a continuous portion of the skull, is connected to it only by ligaments, and suspended in a kind of osseous cavity, formed by the adjacent bones. The cochlea is less developed than in quadrupeds, for it only takes one turn and a half, instead of two and a half. The existence of the se-

* It is probable that in these animals the principal channel by which sounds reach the internal organs is the Eustachian tube.

micircular canals in the cetacea was denied by Camper; but they have since been discovered by Cuvier.

Several quadrupeds, which are in the habit of burrowing, or of diving, as the *Sorex fodiens*, or water-shrew, are furnished with a valve, composed of a double membrane, capable of accurately closing the external opening of the meatus, and protecting it from the introduction of water, earth, or other extraneous bodies.* In like manner the external ear of the *Hippopotamus*, which feeds at the bottom of rivers, is guarded by an apparatus which has the effect of a valve.

We find, indeed, the same provident care displayed in this as in every other department of the animal economy: every part, however minute, of the organ of this important sense, being expressly adapted, in every species, to the particular circumstances of their situation, and to that degree of acuteness of perception, which is best suited to their respective wants and powers of gratification.†

* Geoffroy St. Hilaire; Mémoires du Muséum, i. 305.

† The Comparative Physiology of the Voice, a function of which the object, in animals as well as in man, is to produce sounds, addressed to the ear, and expressive of their ideas, feelings, desires, and passions, forms a natural sequel to that of Hearing; but Sir Charles Bell having announced his intention of introducing it in his Treatise on the Hand, I have abstained from entering into this extensive subject.

CHAPTER VI.

VISION.

§. 1. *Object of the Sense of Vision.*

To those who study nature with a view to the discovery of final causes, no subject can be more interesting or instructive than the physiology of Vision, the most refined and most admirable of all our senses. However well we may be acquainted with the construction of any particular part of the animal frame, it is evident that we can never form a correct estimate of the excellence of its mechanism, unless we have also a knowledge of the purposes to be answered by it, and of the means by which those purposes can be accomplished. Innumerable are the works of creation, the art and contrivance of which we are incompetent to understand, because we perceive only the ultimate effects, and remain ignorant of the operations by which those effects are produced. In attempting to investigate these obscure functions of the animal or vegetable economy, we might fancy ourselves engaged in the perusal of a volume, written in some unknown language, where we have penetrated the meaning of a few words and sentences, sufficient to show us that the whole is pregnant with the deepest thought, and conveys a tale of surpassing interest and wonder, but where we are left to gather the sense of connecting passages by the guidance of remote analogies or vague conjecture. Wherever we fortunately succeed in deciphering any continued portion of the discourse, we find it characterized by that perfection of style, and grandeur of conception, which at once reveal a master's hand, and which kindle in us the most ardent desire of supplying the wide chasms perpetually intervening in the mysterious and inspiring narrative. But in the subject which now claims our attention we have been permitted to trace, for a considerable extent, the continuity of the design, and the lengthened series of means employed for carrying that design into execution; and the view which is thus unfolded of the magnificent scheme of creation is calculated to give us the most sublime ideas of THE WISDOM, THE POWER, AND THE BENEVOLENCE OF GOD.

On none of the works of the Creator, which we are permitted to behold, have the characters of intention been more deeply and legibly engraved than on the organ of vision, where the relation of every part to the effect intended to be produced is too evident to be mistaken, and the mode in which they operate is at once placed within the range of our comprehension. Of all the animal structures, this is, perhaps, the one which most admits of being brought into close comparison with the works of human art; for the eye is, in truth, a refined optical instrument, the perfection of which can never be fully appreciated until we have instituted such a comparison; and the most profound scientific investigations of the anatomy and physiology of the eye concur in showing that the whole of its structure is most accurately and skilfully adapted to the physical laws of light, and that all its parts are finished with that mathematical exactness which the precision of the effect requires, and which no human effort can ever hope to approach,—far less to attain.

To the prosecution of this inquiry we are farther invited by the consciousness of the incalculable advantages we derive from the sense of sight, the choicest and most enchanting of our corporeal endowments. The value of this sense must, indeed, appear inestimable, when we consider of how large a portion of our sensitive and intellectual existence it is the intermediate source. Not only has it given us extensive command over the objects which surround us, and enabled us to traverse and explore the most distant regions of the globe, but it has introduced us to the knowledge of the bodies which compose the solar system, and of the countless hosts of stars which are scattered through the firmament, thus expanding our views to the remotest confines of creation. As the perceptions supplied by this sense are at once the quickest, the most extensive, and the most varied, so they become the fittest vehicles for the introduction of other ideas. Visual impressions are those which in infancy, furnish the principal means of developing the powers of the understanding: it is to this class of perceptions that the philosopher resorts for the most apt and perspicuous illustrations of his reasonings; and it is also from the same inexhaustible fountain that the poet draws his most pleasing and graceful, as well as his sublimest imagery.

The sense of Vision is intended to convey to its possessor a knowledge of the presence, situation, and colour of external and distant objects by means of the light which those objects are continually sending off, either spontaneously, or by reflection from other bodies. It would appear that there is only one part of the nervous system so peculiarly organized as to be capable of being affected by luminous rays, and conveying to the mind the sensation of light, and this part is the *Retina*, so named from the thin and delicate membranous net-work, on which the pulpy extremities of the *optic nerves*, establishing an immediate communication between that part and the brain, are expanded.

If the eye were so constructed as to allow the rays of light, which reach it from surrounding objects, simply to impinge on the retina as they are received, the only perception which they could excite in the mind, would be a general sensation of light, proportionate to the total quantity which is sent to the organ from the whole of the opposite hemisphere. This, however, does not properly constitute Vision; for in order that the presence of a particular object in its real direction and position with respect to us, may be recognised, it is necessary that the light, which comes from it, and that light alone, should produce its impression exclusively on some particular part of the retina; it being evident that if the light, coming from any other object, were allowed to act, together with the former, on the same part, the two actions would interfere with one another, and only a confused impression would result. The objects in a room, for example, are all throwing light on a sheet of paper laid on the floor; but this light being spread equally over every part of the surface of the paper, furnishes no means of distinguishing the sources from which each portion of the light has proceeded; or, in other words, of recognising the respective figures, situations, and colours of the objects themselves. We shall now proceed to consider the modifications to be introduced into the structure of the organ, in order to retain these objects.

§ 2. *Modes of accomplishing the Objects of Vision.*

Let us suppose that it were proposed to us, as a problem, to invent an apparatus, by which, availing ourselves of the known properties of light, we might procure the concentration of all the rays proceeding from the respective points of the object to be viewed, on separate points of the retina, and obtain likewise the exclusion of all other rays; and also to contrive that the points of the retina, so illuminated, should have the same relative situations among one another, which the corresponding points of the surrounding objects have in nature. In other words, let us suppose ourselves called upon to devise a method of forming on the retina a faithful delineation, in miniature, of the external scene.

As it is a fundamental law in optics that the rays of light, while they are transmitted through the same medium, proceed in straight lines, the simplest mode of accomplishing the proposed end would be to admit into the eye, and convey to each particular point of the retina, only a single ray proceeding directly from that part of the object which is to be depicted on it, and to exclude all other rays. For carrying this design into effect we have the choice of two methods, both of which we find resorted to by nature under different circumstances.

The first method consists in providing for each of these single rays a separate tube, with darkened sides, allowing the ray which traverses it, and no other, to fall on its respective point of the retina, which is to be applied at the opposite end of the tube. The most convenient form to be given to the surface of the retina, which is to be spread out to receive the rays from all these tubes, appears to be that of a convex hemisphere; and the most eligible distribution of the tubes is the placing them so as to constitute diverging radii, perpendicular, in every part, to the surface of the retina. This arrangement will be understood by reference to Fig. 406, which represents a section of the whole organ: (T, T,) being the tubes disposed in radii every where perpendicular to the convex hemispherical surface of the retina (R.) Thus will an image be formed, composed of the direct rays from each respective point of the objects, to which the tubes are directed; and these points of the image will have among themselves, the same relative situation as the external objects, from which they originally proceeded, and which they will accordingly faithfully represent.

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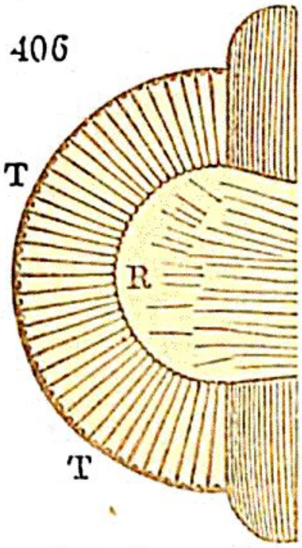

The second method, which is nearly the inverse of the first, consists in admitting the rays through a small aperture into a cavity, on the opposite and internal side of which the retina is expanded, forming a concave, instead of a convex hemispherical surface. The mode in which this arrangement is calculated to answer the intended purpose will be easily understood by conceiving a chamber (as represented in Fig. 407,) into which no light is allowed to enter, except what is admitted through a small hole in a shutter, so as to fall on the opposite side of the room. It is evident that each ray will, in that case, illuminate a different part of the wall, and that the whole external scene will be there faithfully represented; for the several illuminated points, which constitute these images, preserve among themselves the same relative situation which the objects they represent do in nature; although with reference to the actual objects they have an inverted position. This inversion of the image is a necessary consequence of the crossing of all the rays at the same point; namely, the small aperture in the shutter, through which they are admitted.

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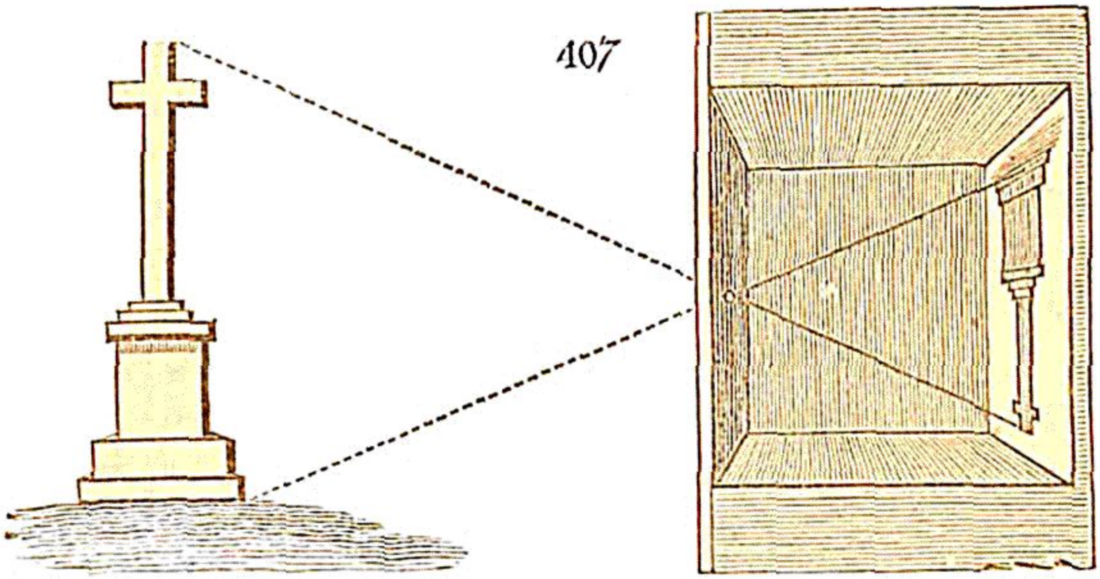

One inconvenience attending the limiting of the illumination of each point of the wall to that of a single ray, in the mode last pointed out, is that the image produced must necessarily be very faint. If, with a view of remedying this defect, the aperture were enlarged, the image would, indeed, become brighter, but would at the same time be rendered more indistinct, from the intermixture and mutual interference of adjacent rays; for all the lines would be spread out, the outlines shaded off, and the whole picture confused.

The only mode by which distinctness of image can be obtained with increased illumination, is to collect into one point a great number of rays proceeding from the corresponding point of the object to be represented. Such a collection of rays proceeding from any point, is termed, in the language of optics, a *pencil of rays;* and the point into which they are collected is called a *focus*. For the purpose of collecting a pencil of rays into a focus, it is evident that all of them, except the one which proceeds in a straight line from the object to that focus, must be *deflected*, or bent from their rectilineal course. This effect may be produced by *refraction*, which takes place according to another optical law; a law of which the following is the exposition.

It is only when the medium which the rays are traversing is of uniform density that their course is constantly rectilineal. If the density change, or if the rays pass obliquely from one medium into another of a different density, they are refracted; each ray being deflected towards a line situated in the medium of greatest density, and drawn from the point where the ray meets the new medium, perpendicular to the refracting surface. Thus, the ray, R, Fig. 408, striking obliquely on the surface of a denser medium, at the point S, instead of pursuing its original course along the line S O, is refracted, or turned in the direction S T, which is a line situated between S O, and S P; this latter line being drawn

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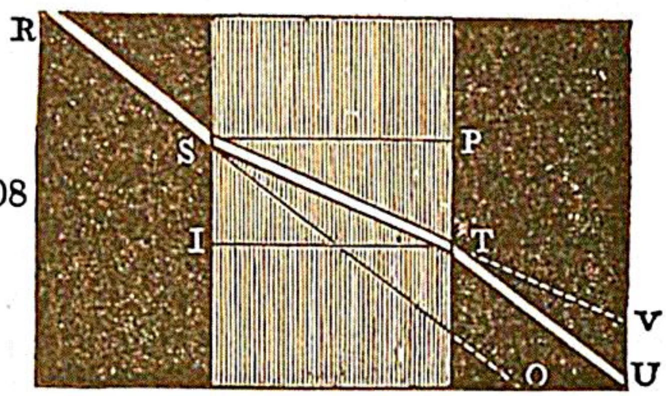
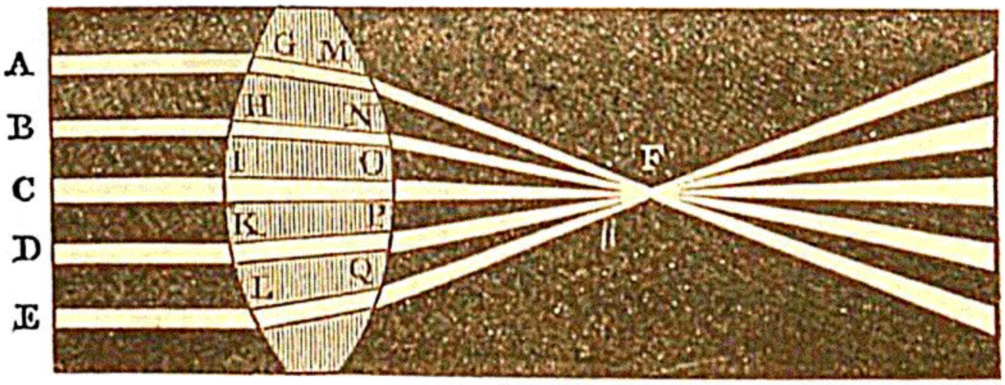


perpendicularly to the surface of the medium, at the point S, and within that medium. When the ray arrives at T, and meets the posterior surface of the dense medium, passing thence into one that is less dense, it is again refracted according to the same law; that is, it inclines towards the perpendicular line T I, drawn from T, within the denser medium, and describes the new course T U instead of T V. The amount of the deflection corresponds to the degree of obliquity of the ray to the surface which refracts it; and is mathematically expressed, by the law, that the sines of the two angles formed with the perpendicular by the incident, and the refracted rays retain, amidst all the variations of those angles, the same constant proportion to one another. We may hence derive a simple rule for placing the plane of the refracting surface so as to produce the particular refraction we wish to obtain. When a ray is to be deflected from its original course to a particular side, we have only to turn the surface of the medium in such a manner as that the perpendicular line to that surface, contained within the denser medium, shall lie still farther on the same side. Thus, in Fig. 408, if we wish to turn the ray R S, from S O to S T, we must place the dense medium so that the perpendicular S P, which is within it, shall be still farther from S O, than S T is; that is, shall lie on the other side of S T. The same rule applies to the contrary refraction of the ray S T from T V to T U, when it passes out of a dense, into a rare medium; for the perpendicular T I must still be placed on the same side of T V as T U is situated.

Let us now apply these principles to the case before us; that is, to the determination of the form to be given to a dense medium, in order to collect a pencil of rays, proceeding from a distant object, accurately to a focus. We shall



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suppose the object in question to be very remote, so that the rays composing the pencil may be considered as being parallel to each other; for at great distances their actual deviation from strict parallelism is wholly insensible; and let A, B, C, D, E, (Fig. 409,) represent these rays. There must evidently be one of these rays (C,) and only one, which, by continuing its rectilineal course, would arrive at the point (R) intended to be the focus of the rays. This ray, then, may be suffered to pass on, without being subjected to any refraction; the surface of the medium should, therefore, be presented to the ray (at I) perpendicularly to its course, so that it may pass through at right angles to that surface. Those rays (B and D) which are situated very near to this direct or central ray (C,) will require but a small degree of refraction in order to reach the focus (R;) this small refraction will be effected by a slight degree of obliquity in the medium at the points (H and K) where those rays meet it. In proportion as the rays (such as those at A and E) are more distant from the central ray, a greater amount of refraction, and consequently a greater obliquity of the surfaces (G and L) will be required, in order to bring them to the same focus.

The convergence of these rays, after they have passed this first surface, which would have brought them to the point R, may be farther increased by interposing new surfaces of other media at the proper angles. If the new medium be still denser than the last, the inclination of its surface must be similar to that already described; if rarer, they must be in an opposite direction. This last case also is illustrated in the figure, where M, N, O, P, Q, show the inclinations of the surfaces of a rarer medium, calculated to increase the convergence of the rays, that is, to bring them to a nearer focus (F.) The result of the continued change of direction in the refracting surface, is a regular curvilineal surface, which, in the present case, approaches very nearly to that of a sphere. Hence by giving these refractive media spherical surfaces, we adapt them, with tolerable exactness, to produce the convergence of parallel rays to a focus, and by making the denser medium convex on both sides (as shown in Fig. 410,) both surfaces will conspire in producing the desired effects. Such an instrument is termed a *double convex lens;* and it has the property of collecting into a focus rays proceeding from distant points.*

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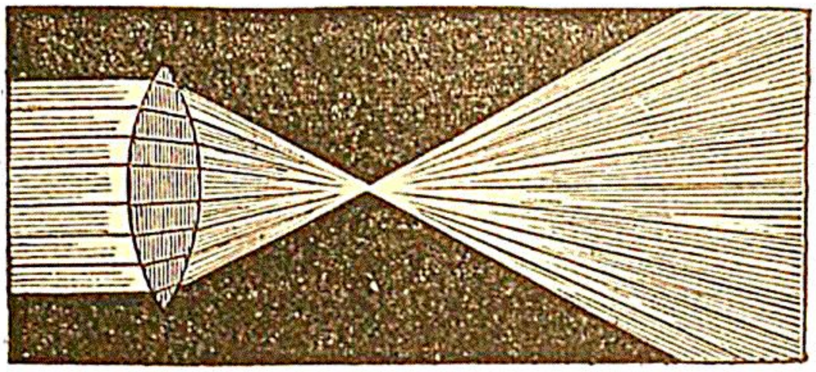

Having obtained this instrument, we may now venture to enlarge the aperture through which the light was admitted into our dark chamber, and fit into the aperture a double convex lens. We have thus constructed the well known optical instrument called the *Camera Obscura,* in which the images of external objects are formed upon a white surface of paper, or a semi-transparent plate of glass; and these images must evidently be in an inverted position with respect to the actual objects which they represent.

Such is precisely the construction of the eye, which is, to

* The refraction by spherical surfaces does not, strictly speaking, unite a pencil of parallel or divergent rays into a mathematical point, or focus; for in reality the rays which are near the central line are made to converge to a point a little more distant than that to which the remoter rays converge: an effect which I have endeavoured to illustrate by the diagram Fig. 411; where,

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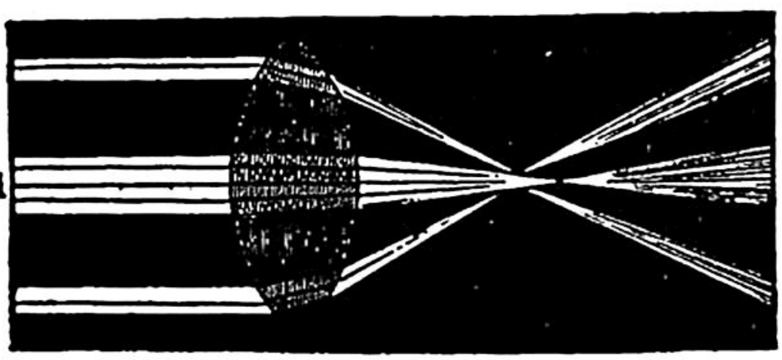

in order to render it obvious to the eye, the disparity is exaggerated; for, on ordinary occasions, where great nicety is not required, this difference in the degree of convergence between the central rays and those near the circumference of the lens, giving rise to what is termed the *Aberration of Sphericity,* is too small to attract notice.

all intents, a camera obscura: for in both these instruments, the objects, the principles of construction, and the mode of operation are exactly the same; and the only difference is, that the former is an infinitely more perfect instrument than the latter can ever be rendered by the utmost efforts of human art.

§ 3. *Structure of the Eye.*

ONE of the many points of superiority which the eye possesses over the ordinary camera obscura is derived from its spherical shape, adapting the retina to receive every portion of the images produced by refraction, which are themselves curved; whereas, had they been received on a plane surface, as they usually are in a camera obscura, a considerable portion of the image would have been indistinct. This spherical form is preserved by means of the firm membranes which protect the eye, and which are termed its *Coats;* and the transparent media which they enclose, and which effect

With a view of simplifying the subject, I have assumed, in the account given in the text, that the rays which arrive at the eye are parallel, which in mathematical strictness they never are. The focus of the rays refracted by

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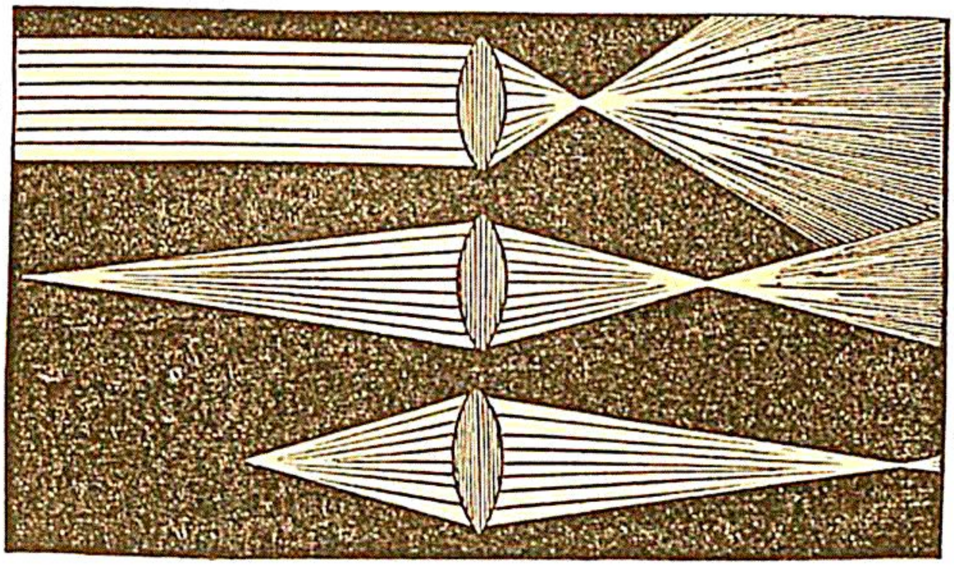

a convex lens is more remote in proportion as the rays are more divergent, or, in other words, proceed from nearer objects. This is illustrated by Figures 412, 413, and 414; to which I shall again have occasion to refer in the sequel.

the convergence of the rays, are termed the *Humours of the Eye*. There are in this organ three principal coats, and three humours, composing altogether what is called the *Globe of the Eye*. Fig. 415, which gives an enlarged view of a horizontal section of the right eye, exhibits distinctly all these parts.

The outermost coat (s,) which is termed the *Sclerotica*, is exceedingly firm and dense, and gives to the globe of the eye the mechanical support it requires for the performance of its delicate functions. It is perforated behind by the optic nerve (o,) which passes onwards to be expanded into the retina (R.) The sclerotica does not extend farther than about four-fifths of the globe of the eye; its place in front being supplied by a transparent convex membrane (c,) called the *Cornea*, which is more prominent than the rest of the eye-

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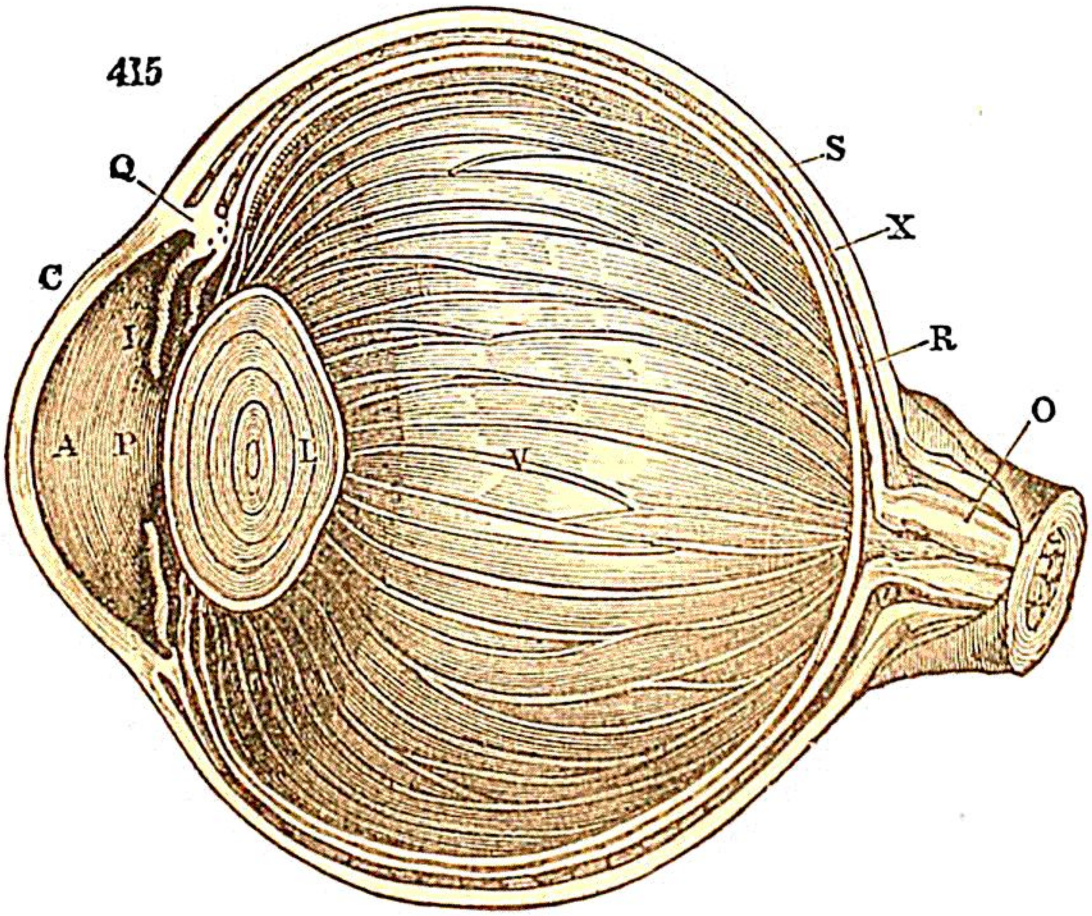

ball. A line passing through the centre of the cornea and the centre of the globe of the eye, is called the *axis* of the eye. The Sclerotica is lined internally by the *Choroid coat* (x,) which is chiefly made up of a tissue of blood vessels, for supplying nourishment to the eye. It has on its inner surface a layer of a dark coloured viscid secretion, known by the name of the *Pigmentum nigrum*, or black pigment. Its use is to absorb all the light which may happen to be irregularly scattered through the eye, in consequence of reflection from different quarters; and it serves, therefore, the same purpose as the black paint with which the inside of optical instruments, such as telescopes, microscopes, and cameræ obscuræ, is darkened. Within the pigmentum nigrum, and almost in immediate contact with it,* the *Retina* (R) is expanded, forming an exceedingly thin and delicate layer of nervous matter, supported by a fine membrane.

More than three-fourths of the globe of the eye are filled with the *vitreous humour* (V,) which has the appearance of a pellucid and elastic jelly, contained in an exceedingly delicate texture of cellular substance. The *Crystalline humour*, (L,) which has the shape of a double convex lens, is formed of a denser material than any of the other humours, and occupies the fore part of the globe of the eye, immediately in front of the vitreous humour, which is there hollowed to receive it. The space which intervenes between the lens and the cornea is filled with a watery secretion (A,) called the *Aqueous humour*. This space is divided into an anterior and a posterior chamber by a flat circular partition (I,) termed the *Iris*.

The iris has a central perforation (P,) called the *Pupil*, and it is fixed to the edge of the choroid coat, by a white elastic ring (Q,) called the *Ciliary Ligament*. The posterior surface of the iris is called the *Uvea*, and is lined with a dark brown pigment. The structure of the iris is very peculiar, being composed of two layers of contractile fibres; the one, forming concentric circles; the other, disposed like radii between the outer and inner margin.† When the

* Between the pigmentum and the retina there is found a very fine membrane, discovered by Dr. Jacobson: its use has not been ascertained.

† See Fig. 47, vol. i. p. 105.

former act, the pupil is contracted; when the latter act, the breadth of the iris is diminished, and the pupil is, of course, dilated. By varying the size of the pupil the quantity of light admitted into the interior of the eye is regulated, and accommodated to the sensibility of the retina. When the intensity of the light would be injurious to that highly delicate organ, the pupil is instantly contracted, so as to exclude the greater portion; and, on the contrary, when the light is too feeble, it is dilated, in order to admit as large a quantity as possible. The iris also serves to intercept such rays as would have fallen on parts of the crystalline lens less fitted to produce their regular refraction, the object of which will be better understood when we have examined the functions of this latter part. But, before engaging in this inquiry, it will be proper to complete this sketch of the Anatomy of the Eye by describing the principal parts of the apparatus belonging to that organ, which are exterior to the eye-ball, and may be considered as its appendages.

The purposes answered by the parts exterior to the eye-ball are chiefly those of motion, of lubrication, and of protection.

As it is the central part of the retina which is endowed with the greatest share of sensibility, it is necessary that the images of the objects to be viewed should be made to fall on this part; and, consequently, that the eye should be capable of having its axis instantly directed to those objects, wherever they may be situated. Hence, muscles are provided within the orbits, for effecting the motions of the eye-ball. A view of these muscles, with their attachments to the ball of the eye, but separated from the other parts, is given in Fig. 416. Four of these proceed in a straight course from the bottom of the orbit, arising from the margin of the aperture through which the optic nerve passes, and being inserted by a broad tendinous expansion into the

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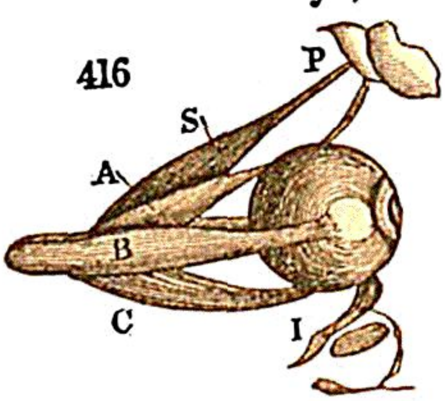

fore part of the sclerotic coat. Three of these are marked A, B, and C, in the figure; and the edge of the fourth is seen behind and above B. These *straight muscles*, as they are called, surround the optic nerve and the eye-ball, forming four longitudinal bands; one (A) being situated above for the purpose of turning the eye upwards; a second (C,) situated below, for turning it downwards; and the two others, on either side, for performing its lateral motions to the right or left. The cavity of the orbits being considerably larger than the eye-ball, the intervening space, especially at the back part, is filled up by fat, which serves as a soft cushion for its protection, and for enabling it to roll freely in all directions.

Besides these straight muscles, there are also two others (S and I) termed the *oblique muscles*, which give the eye-ball a certain degree of rotation on its axis. When these act in conjunction, they draw the eye forwards, and serve as antagonists to the combined power of the straight muscles. The upper oblique muscle (S) is remarkable for the artificial manner in which its tendon passes through a cartilaginous pulley (P) in the margin of the orbit, and then turns back again to be inserted into the eye-ball, so that the effect produced by the action of the muscle is a motion in a direction exactly the reverse of that in which its fibres contract. This mechanism, simple as it is, affords one of the most palpable instances that can be adduced of express contrivance; for in no other situation could the muscle have been so conveniently lodged as within the eye-ball; and in no other way could its tendon have been made to pull in a direction contrary to that of the muscle, than by the interposition of a pulley, turning the tendons completely round.

The fore-part of the globe of the eye, which is of a white colour, is connected with the surrounding integuments by a membrane, termed the *Conjunctiva*.* This membrane, on

* An abundant supply of nerves has been bestowed on this membrane for the purpose of conferring upon it that exquisite degree of sensibility which

arriving at the base of the eye-lids, is folded forwards so as to line their inner surfaces, and to be continuous with the skin which covers their outer sides. The surfaces of the conjunctiva and of the cornea are kept constantly moist by the tears, which are as constantly secreted by the *Lacrymal glands.* Each gland, (as shown at L, Fig. 417,) is si-

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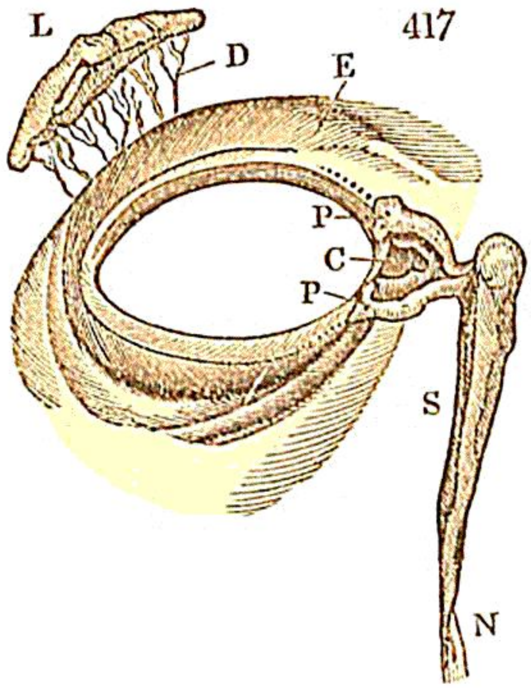

tuated above the eye, in a hollow of the orbit, and the ducts (D) proceeding from it open upon the inner side of the upper eye-lid (E.) This fluid, the uses of which are obviously to wash away dust, or other irritating substances which may happen to get intróduced, is distributed over the outer surface of the eye by means of the eye-lids. Each lid is supported by an elastic plate of cartilage, shaped like a crescent, and covered by integuments. An orbicular muscle, the fibres of which run in a circular direction, immediately underneath the skin, all round the eye,* is provided for closing them. The upper eye-lid is raised by a separate muscle, contained within the orbit, immediately above the

was necessary to give immediate warning of the slightest danger to so important an organ as the eye from the intrusion of foreign bodies. That this is the intention is apparent from the fact that the internal parts of the eye possess but little sensibility compared with the external surface.

* See Fig. 46, vol. i. p. 105.

upper straight muscle of the eye-ball. The eye-lashes are curved in opposite directions, so as not to interfere with each other when the eye-lids are closed. Their utility in guarding the eye against the entrance of various substances, such as hairs, dust, or perspiration, and also in shading the eye from too strong impressions of light, is sufficiently apparent. The eye-lids, in closing, meet first at the outer corner of the eye; and their junction proceeds along the line of their edges, towards the inner angles, till the contact is complete: by this means the tears are carried onwards in that direction, and accumulated at the inner corner of the eye, an effect which is promoted by the bevelling of the margins of the eye-lids, which, when they meet, form a channel for the fluid to pass in that manner. When they arrive at the inner corner of the eye, the tears are conveyed away by two slender ducts, the orifices of which, called the *puncta lacrymalia* (P, P,) are seen at the inner corner of each eye-lid, and are separated by a round projecting body (C,) connected with a fold of the conjunctiva, and termed the *lacrymal caruncle*. The two ducts soon unite to form one passage, which opens into a sac (S,) situated at the upper part of the sides of the nose, and terminating below (at N) in the cavity of the nostrils, into which the tears are ultimately conducted. When the secretion of the tears is too abundant to be carried off by this channel, they overflow upon the cheeks; but when the quantity is not excessive, the tendency to flow over the eye-lid is checked by an oily secretion proceeding from a row of minute glands, situated at the edge of the eye-lids, and termed the *Meibomian glands.*

The eye-brows are a farther protection to the eyes, the direction of the hairs being such as to turn away from them any drops of rain or of perspiration which may chance to fall from above.

Excepting in front, where the eyes are covered and protected by the eye-lids, these important organs are on all sides effectually guarded from injury by being contained in a hollow bony socket, termed the orbit, and composed of seven portions of bone. These seven elements may be recognised in the skulls of all the mammalia, and perhaps also in those of all other vertebrated animals, affording a remarkable illustration of the unity of the plans of nature in the construction of the animal fabric.

§ 4. *Physiology of perfect Vision.*

The rays of light, proceeding from a distant object, strike upon the convex surface of the cornea, which being of greater density than the air, refracts them, and makes them converge towards a distant focus. This effect, however, is in part counteracted on their emergence from the concave posterior surface of the cornea, when the rays enter into the aqueous humour. On the whole, however, they are refracted, and made to converge to a degree equal to that which they would have undergone if they had at once impinged against the convex surface of the aqueous humour, supposing the cornea not to have been interposed.

A considerable portion of the light which has thus entered the aqueous humour is arrested in its course by the iris; so that it is only those rays which are admitted through the pupil that are subservient to vision. These next arrive at the crystalline lens, where they undergo two refractions, the one at the anterior, the other at the posterior surface of that body. Both these surfaces being convex outwardly, and the lens being a denser substance than either the aqueous or the vitreous humours, the effect of both these refractions is to increase the convergence of the rays, and to bring them to unite in a focus on the retina at the bottom of the eye. The most considerable of these refractions is the first; because the difference of density between the air and the cornea, or rather the aqueous humour, is greater than that of any of the humours of the eye compared with one another.

The accurate convergence of all the rays of light, which enter through the pupil, to their respective foci on the retina, is necessary for the perfection of the images there formed; but, for the complete attainment of this end, various nice adjustments are still requisite.

In the first place, the *Aberration of Sphericity*,* which is a consequence of the geometrical law of refraction, introduces a degree of confusion in the image; which is scarcely perceptible, indeed, on a small scale, but which become sensible in instruments of much power; being one of the greatest difficulties which the optician has to overcome in the construction of the telescope and the microscope. Nature, in framing the human eye, has solved this difficulty by the simplest, yet most effectual means, and in a manner quite inimitable by human art. She has, in the first place, given to the surfaces of the crystalline lens, instead of the spherical form, curvatures more or less hyperbolical or elliptical; and has, in the next place, constructed the lens of an infinite number of concentric layers, which increase in their density, as they succeed one another from the surface to the centre. The refracting power, being proportional to the density, is thus greatest at the centre, and diminishes as we recede from that centre. This admirable adjustment exactly corrects the deficiency of refraction, which always takes place in the central portions of a lens composed of a material of uniform density, as compared with the refraction of the parts more remote from the centre.†

The second adjustment for perfect vision has reference to the variations in the distance of the focus which take place according as the rays arrive at the eye from objects at different distances, and which may be called the *Aberrations of*

* See Fig. 411, and the note referring to it, p. 324.

† Sir David Brewster has ascertained that the variations of density producing the doubly refracting structure, in the crystalline lens of fishes, are related, not to the centre of the lens, but to the diameter which forms the axis of vision: an arrangement peculiarly adapted for correcting the spherical aberrations. Philos. Trans. for 1816, p. 317.

Parallax. When the distance of the object is very great, the rays proceeding from each point arrive at the eye with so little divergence, that each pencil may be considered as composed of rays which are parallel to each other; the actual deviation from parallelism being quite insensible. But if the same object be brought nearer to the eye, the divergence of the rays becomes more perceptible; and the effect of the same degree of refraction is to collect them into a focus more remote than before.* For every distance of the object there is a corresponding focal distance; and when the eye is in a state adapted for distinct vision at one distance, it will have confused images of objects at another distance; because the exact foci of the rays will be situated either before or behind the retina. It is evident that if the retina be not placed exactly at the point where the focus is situated, it will either intercept the pencil of rays before they are united into a point, or receive them after they have crossed one another in passing through the focus: in either of which cases, each pencil will throw upon the retina a small circle of light, brighter at the middle and fainter at the edges, which will mix itself with the adjacent pencils, and create confusion in the image.

It is found, however, that the eye has a power of accommodating itself to the distinct vision of objects at a great variety of distances, according as the attention of the mind is directed to the particular object to be viewed. The mode in which this change in the state of the eye is effected has been the subject of much controversy. The increase of the refracting power of the eye necessary to adapt it to the vision of near objects is evidently the result of a muscular effort, of which we are distinctly conscious when we accurately attend to the accompanying sensations. The researches of

* This is illustrated by Fig. 412, 413, and 414; the first of which shows the rapid convergence of rays proceeding from a very distant object, and which may be considered as parallel. The second shows that divergent rays unite at a more distant focus; and the third, that the focus is more distant the greater the divergence.

Dr. Young have rendered it probable that some change takes place in the figure of the lens, whereby its convexity, and perhaps, also, its distance from the retina, are increased. He has shown, by a very decisive experiment, that any change which may take place in the convexity of the cornea has but little share in the production of the effect; for the eye retains its power of adaptation when immersed in water, in which the form of the cornea can in no respect influence the refraction.

But the rays of light are of different kinds; some exciting the sensation of red, others of yellow, and others again of blue; and these different species of light are refracted, under similar circumstances, in different degrees. Hence, the more refrangible rays, that is, the violet and the blue, are brought to a nearer focus, than those which are less refrangible, that is, the orange and the red rays; and this want of coincidence in the points of convergence of these different rays, (all of which enter into the composition of white light,) necessarily impairs the distinctness of all the images produced by refraction, shading off their outlines with various colours, even when the object itself is colourless. This defect, which is incident to the power of a simple lens, and which is termed the *Chromatic Aberration*, is remedied almost perfectly in the eye, by the nice adjustment of the powers of the different refracting media, which the rays of light have to traverse before they arrive at the retina, producing what is called an *achromatic* combination;* and it is found that the eye, though not an absolutely achromatic instrument, as was asserted by Euler,† is yet sufficiently so for all the ordinary practical purposes of life.

The object, then, of the whole apparatus appended to the optic nerve, is to form inverted images of external objects on the retina, which, as we have seen, is the expanded ex-

* For the exposition of the principles on which these achromatic combinations of lenses correct this source of aberration, I must refer to works which treat professedly on Optics.

† For the rectification of this error we are indebted to Dr. Young.

tremity of that nerve. That this effect is actually produced, *may be easily shown by direct observation; for if the sclerotic* and choroid coats be carefully dissected off from the posterior part of the eye of an ox, or any other large quadruped, leaving only the retina, and the eye so prepared be placed in a hole in a window-shutter, in a darkened room, with the cornea on the outside, all the illuminated objects of the external scene will be beautifully depicted, in an inverted position, on the retina.

Few spectacles are more calculated to raise our admiration than this delicate picture, which nature has, with such exquisite art, and with the finest touches of her pencil, spread over the smooth canvass of this subtle nerve; a picture, which, though scarcely occupying a space of half an inch in diameter, contains the delineation of a boundless scene of earth and sky, full of all kinds of objects, some at rest, and others in motion, yet all accurately represented as to their forms, colours, and positions, and followed in all their changes, without the least interference, irregularity, or confusion. Every one of those countless and stupendous orbs of fire, whose light, after traversing immeasurable regions of space, at length reaches our eye, is collected on its narrow curtain into a luminous focus of inconceivable minuteness; and yet this almost infinitesimal point shall be sufficient to convey to the mind, through the medium of the optic nerve and brain, a knowledge of the existence and position of the far distant luminary, from which that light has emanated. How infinitely surpassing all the limits of our conception must be the intelligence, and the power of that Being, who planned and executed an instrument comprising, within such limited dimensions, such vast powers as the eye, of which the perceptions comprehend alike the nearest and most distant objects, and take cognizance at once of the most minute portions of matter, and of bodies of the largest magnitude!

§ 5. *Comparative Physiology of Vision.*

In the formation of every part of the animal machinery we may generally discern the predominance of the law of gradation; but this law is more especially observed in those organs which exhibit, in their most perfect state, the greatest complication and refinement of structure; for on following all their varieties in the ascending series, we always find them advancing by slow gradations of improvement, before they attain their highest degree of excellence. Thus, the organ of vision presents, amidst an infinite variety of constructions, successive degrees of refinement, accompanied by corresponding extensions of power. So gradual is the progress of this development, that it is not easy to determine the point where the faculty of vision, properly so called, begins to be exercised, or where the first rudiment of its organ begins to appear.

Indications of a certain degree of sensibility to light are afforded by many of the lower tribes of Zoophytes, while no visible organ appropriated to receive its impressions can be traced. This is the case with many microscopic animalcules; and still more remarkably with the *Hydra*, and the *Actinia*, which show by their movements that they feel the influence of this agent; for, when confined in a vessel, they always place themselves, by preference, on the side where there is the strongest light.* The *Veretillum cynomorium*, on the other hand, seeks the darkest places, and contracts itself the moment it is exposed to light.† In a perfectly calm sea, the *Medusæ* which are rising towards the surface, are seen to change their course, and to descend again, as soon as they reach those parts of the water which receive the full influence of the sun's rays, and before any part of

* Such is the uniform report of Trembley, Baker, Bonnet, Goëze, Hanow, Rœsel, and Schæffer.

† Rapp; Nov. Act. Acad. Nat. Cur. of Bonn, xiv. 645.

their bodies has come into contact with the atmosphere.* But, in all these instances a doubt may arise whether the observed actions may not be prompted by the mere sensation of warmth excited by the calorific rays which accompany those of light; in which case they would be evidence only of the operation of a finer kind of touch.

The first unequivocal appearance of visual organs is met with in the class of Annelida; although the researches of Ehrenberg would induce us to believe that they may be traced among animals yet lower in the scale; for he has noticed them in several of the more highly organized Infusoria, belonging to the order Rotifera, and particularly in the *Hydatina senta*, where he has found the small black points observable in other species, united into a single spot of larger size. Nitsch, also, states that the *Cercaria viridis* possesses three organs of this kind. *Planariæ* present two or three spots, which have been regarded as visual organs; and these have been found by Baer to be composed, in the *Planaria torva*, of clusters of black grains, situated underneath the white or transparent integument.† The eyes of the *Nais proboscidea* are composed, according to Gruithuisen, simply of a small mass of black pigment, attached to the extremity of the optic nerve;‡ and organs apparently similar to these are met with in many of the inferior tribes of Annelida. In all these cases it is a matter of considerable doubt whether the visual organs are constructed with any other intention than merely to convey general sensations of light, without exciting distinct perceptions of the objects themselves from which the light proceeds; this latter purpose requiring, as we have seen, a special optical apparatus of some degree of complexity. An approach to the formation of a crystalline lens takes place in the genus *Eunice* of Cuvier, (*Lycoris*, Sav.,) which, from the

* Grant; Edin. Journal of Science: No. 20.

† Nov. Act. Acad. Nat. Cur. of Bonn, xiii. 712. See also the Memoir of Dugès, entitled "Recherches sur l'Organisation et les Mœurs des Planaires," in the Annales des Sc. Nat. xv. 148.

‡ Nov. Act. Acad. Nat. Cur. of Bonn, xi. 242.

account given by Professor Muller,* has four eyes, situated on the hinder part of the head, and covered with the epidermis, but containing in their interior a spherule, composed of an opaque white substance, surrounded by a black pigment, and penetrated by an optic nerve, which is continued to the brain. On the other hand, Professor Weber found in the *Hirudo medicinalis*, or common leech, no less than ten minute eyes, arranged in a semicircle, in front of the head, and projecting a little from the surface of the integument: they present externally a convex, and perfectly transparent cornea; while internally, they are prolonged into cylindrical tubes containing a black pigment;† structures, apparently subservient to a species of vision of a higher order than that which consists in the simple recognition of the presence of light.

No organs having the most distant relation to the sense of vision have ever been observed in any of the Acephalous, or bivalve Mollusca; but various species of Gasteropoda have

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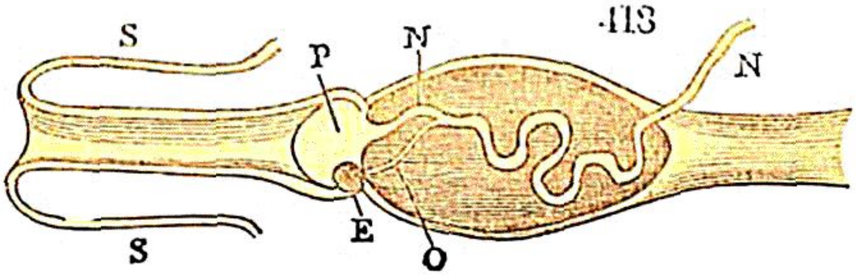

organs which appear to exercise this sense, situated sometimes at the base, sometimes at the middle, and frequently at the extremity of the tentacula. Of the latter we have examples in the common slug and snail, where these tentacula, or horns, are four in number, and are capable of being protruded and again retracted, by folding inwards like the finger of a glove, at the pleasure of the animal. According to Muller,‡ the eye of the *Helix pomatia*, represented at E, (Fig. 418,) is situated a little to one side of the rounded extremity, or papilla (P,) of the tentaculum, and is attached to an

* Annales des Sciences Naturelles, xxii. 23.

† Meckel, Archiv. für Anatomie und Physiologie; 1824, p. 301.

‡ Annales des Sciences Naturelles; xxii. 12.

oval bulb of a black colour. It receives only a slender branch (o) from a large nerve (N N) which is distributed to the papilla of the tentaculum, and appears to be appropriated exclusively to the sense of touch. The bulb, with the eye attached to it, is represented, in this figure, as half retracted within the tubular sheath of the tentaculum (s s;) but it can exercise its proper function only when fully exposed, by the complete unfolding and protrusion of the tentaculum. This eye contains within its choroid coat, a semi-fluid and perfectly transparent substance, filling the whole of the globe; and Muller also discovered at the anterior part, another transparent body, having the shape of a lens.* A structure very similar to this was found to exist in the eye of the *Murex tritonis*, with the addition of a distinct iris, perforated so as to form a pupil; a part which had also been observed, together with a crystalline lens of very large size, in the *Voluta cymbium*, by De Blainville.† Thus, the visual organs of these Gasteropoda appear to possess every requisite for distinct vision, properly so called. Experiments are said to have been recently made, both by Leuchs, and by Steifensand,‡ in which a snail was repeatedly observed to avoid a small object presented near the tentaculum; thus affording evidence of its possessing this sense.

The accurate investigation of the anatomy of the eyes of insects presents considerable difficulty, both from the minuteness of their parts and from the complication of their structure; so that notwithstanding the light which has recently been thrown on this interesting subject by the patient and laborious researches of entomologists, great obscurity still prevails with regard to the mode in which these dimi-

* Muller thus confirms the accuracy of Swammerdam's account of the anatomy of the eye of the snail, which had been contested by Sir E. Home (Phil. Trans. 1824, p. 4,) and other writers.

† Principes d'Anatomie Comparée, i. 445.

‡ Quoted by Muller; ibid. p. 16. These results also corroborate the testimony of Swammerdam, who states that he had obtained proofs that the snail could see by means of these organs.

nutive beings exercise the sense of vision. Four descriptions of visual organs are met with in the class of Articulated Animals; the first are the simple eyes, or *stemmata*, as they are termed, which appear as lucid spots, resembling those we have noticed in the higher orders of Annelida; the second, are the *conglomerate* eyes, which consist of clusters or aggregations of simple eyes; the third, are the *compound* eyes, which are formed of a vast assemblage of small tubes, each having its respective apparatus of humours, and of retina, and terminating externally in a separate cornea, slightly elevated above the general surface of the organ: the fourth kind of eyes, which have not yet been distinguished by any particular appellation, are constituted by a number of separate lenses, and subjacent retinæ, but the whole covered by a single cornea common to them all.

Few insects are wholly destitute of visual organs, either in their larva or perfect states.* The larvæ of those insects which undergo a complete metamorphosis have only stemmata; but those which are subjected only to a partial change of form, as the Orthoptera, the Hemiptera, and the aquatic Neuroptera, have compound as well as simple eyes. Perfect insects, with the few exceptions above noticed, have always compound eyes, generally two in number, placed on the sides of the head; and they are often accompanied by stemmata situated between, or behind them, on the upper part of the head. These stemmata, when met with, are generally three in number, and are either placed in a row, or form a triangle. Their structure has been minutely examined by Professor Muller, who found them to contain a hard and spherical crystalline lens, a vitreous humour, and a choroid coat, with its accompanying black pigment; the whole being covered externally by a convex cornea. The stemmata of

* This is the case, however, with the genus *Claviger*, among the Coleoptera *Braula* (Nitzch) among Diptera, and also some of the species of *Pupipara*, *Nycteribia*, and *Melophagus*, which are all parasitic insects: there are also five species of ants, whose neuters have no eyes. (Muller, Annales des Sc. Nat. xvii. 366.)

a caterpillar, which has eight of these eyes, are shown in Fig. 419, connected together by a circular choroid mem-

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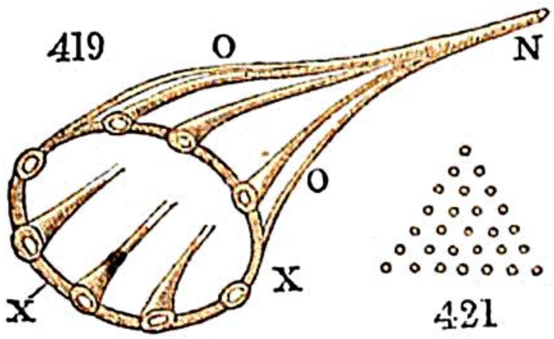

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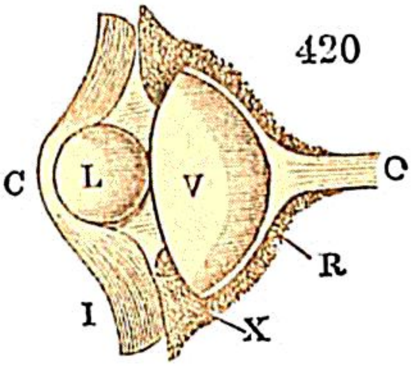

brane (x x) common to the whole: together with the separate branches (o o) of the optic nerve (N) belonging to each.

All the Arachnida possess eyes of this latter description; and from their greater size afford facilities for dissection, which are not met with among proper insects. Their number in Spiders is generally eight, and they are disposed with great symmetry on the upper side of the head. Fig. 420 represents, on a magnified scale, one of the large stemmata, on the head of the *scorpio tunensis*, dissected so as to display its internal parts; in which are seen the cornea (C,) derived from an extension of the integument (I;) the dense spherical crystalline lens (L;) the choroid coat with its pigment (x,*) forming a wide opening, or pupil; the vitreous humour (V,) covered behind by the retina (R,) which is closely applied to it; and the optic nerve (O,) with which the retina is continuous.

Examples of the conglomerate eye occur in the Myriapoda: in the *Scolopendra*, for instance, they consist of about twenty contiguous circular pellucid lenses, arranged in five lines, with one larger eye behind the rest, which Kirby compares to a sentinel, or scout, placed at some little distance from the main body. In the *Julis terrestris*, or common Millepede, these eyes, amounting to 28, form a triangle, be-

* Marcel de Serres states, that some of the stemmata of the insects which he examined contain a thin choroid, having a silvery lustre, as if intended as a reflector of the light which falls on it.

ing disposed in seven rows, the number in each regularly diminishing from the base to the apex; an arrangement which is shown in Fig. 421.*

The compound eyes of insects are formed of a vast number of separate cylinders or elongated cones,† closely packed together on the surface of a central bulb, which may be considered as a part of the optic nerve; while their united bases or outer extremities constitute the surface of a hemispherical convexity, which often occupies a considerable space on each side of the head. The usual shape of each of these bases is that of a hexagon, a form which admits of their uniform arrangement with the greatest economy of space, like the cells of a honey-comb; and the hexagonal divisions of the surface are very plainly discernible on viewing the surface of these eyes with a microscope, especially as there is a thin layer of black pigment intervening between each, like mortar between the layers of brick. The appearance they present in the *Melolontha*, when highly magnified, is shown in Fig. 422.‡ The internal structure of these eyes will be best understood from the section of that of the *Libellula vulgata*, or gray Dragon-fly, shown in Fig. 424, aided by the highly magnified views of smaller portions given in the succeeding figures, in all of which the same letters of reference are used to indicate the same objects.§ The whole outer layer (c c) of the compound eye may be considered

* Kirby and Spence's Introduction, &c., iii. 494.

† The number of these cones or cylinders which compose the entire organ differs much in different species. In the ant, there are only 50; in a *Scarabæus*, 3180; in the *Bombyx mori*, 6236; in the house-fly (Musca domestica,) 8000; in the *Melolontha vulgaris*, 8820; in the *Phalena cossus*, 11,300; in the *Libellula*, 12,544; in the *Papilio*, 17,325; and in the *Mordella*, 25,088.

‡ In the *Phalenæ*, and other tribes, they are arranged in squares (as shown in Fig. 423,) instead of hexagons, and frequently much less regularly; as must necessarily happen, in many parts, from the curvature of the spherical surface.

§ These figures, as well as the account of the anatomy of the eye of the Libellula, are taken from the memoir of Dugès, in the Annales des Sciences Naturelles, xx. 341.

as corresponding to the cornea; each separate division of which has been termed a *Corneule*, being composed of a horny and perfectly transparent material. Each corneule

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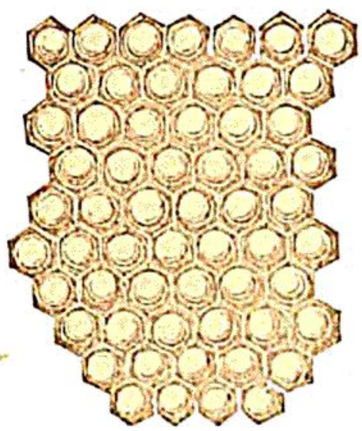

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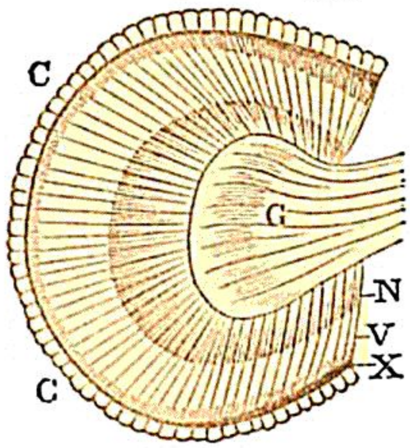

(c) has the form of a truncated pyramid, the length of which (L) is between two and three times the diameter of the base (B.) The outer surface (B) is very convex; but the internal or truncated end (D) is concave; and the concavity of the latter being smaller than the con-

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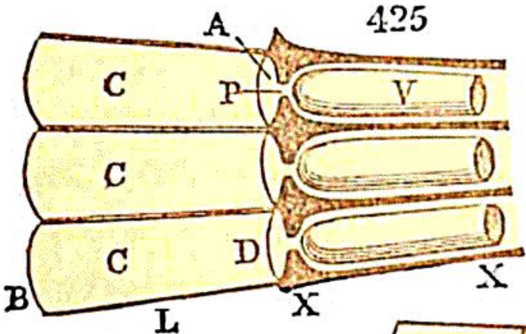

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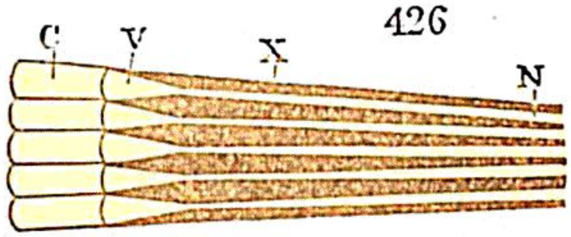

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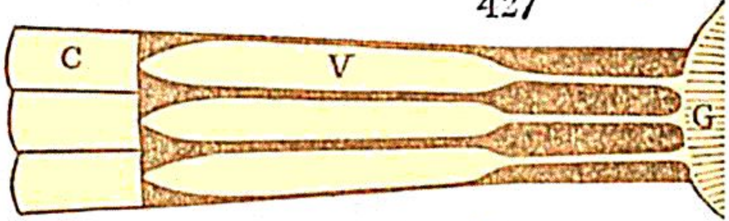

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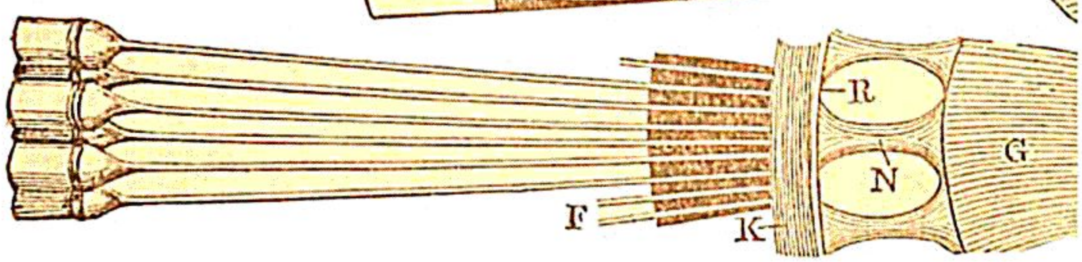

vexity of the former, its optical effect is that of a *meniscus*, or concavo-convex lens, with power of converging to a distant focus the rays of light which traverse it. Within these corneules there is extended a layer of an opaque black pigment (X,) probably connected with a choroid coat, which, from the delicacy of its texture, has hitherto escaped observation. There exists opposite to the centre, or axis of each corneule, a circular perforation (P,) which performs the functions of a pupil.* Dugès states, indeed, that he has witnessed in this part movements of contraction and dilatation, like those of the iris in vertebrated animals. He has likewise found that there is a small space (A) intervening between the extremity of each corneule and the iris, and filled with an aqueous humour. The compartments formed by the substance of the choroid (X) are continued inwards towards the centre of the general hemisphere, the cylindrical spaces which they enclose being occupied each by a transparent cylinder (V,) consisting of an outer membrane, filled with a viscid substance analogous to the vitreous humour. Their general form and situation, as they lie imbedded in the pigment, may be seen from the magnified sections; each cylinder commencing by a rounded convex base, immediately behind its respective pupil, and slightly tapering to its extremities, where it is met by a filament (N) of the optic nerve; and all these filaments, after passing for a certain distance through a thick mass of pigment, are united to the large central nervous bulb (G, Fig. 427,) which is termed the *optic ganglion*.†

* This pupillary aperture was discovered by Muller, after it had eluded all the efforts of former observers to detect it; and it was accordingly the prevailing notion that the black pigment lined the whole surface of the cornea, and interposed an insuperable barrier to the passage of light beyond the cornea. It was evidently impossible, while such an opinion was entertained, that any intelligible theory of vision, with eyes so constructed, could be formed.

† Numberless modifications of the forms of each of these constituent parts occur in different species of insects. Very frequently the vitreous humour (V,) instead of forming an elongated cylinder, has the shape of a short cone, terminating in a fine point, as shown in Fig. 426. Straus Durckheim appears to have mistaken this part for an enlarged termination of the optic nerve, believing it to be opaque, and to form a retina applied to the back of the corneule, which latter part he considered as properly the crystalline lens. In his elaborate work on the anatomy of the Melolontha, he describes the

It thus appears that each of the constituent eyes, which compose this vast aggregate, consists of a simple tube, furnished with all the elements requisite for distinct vision, and capable of receiving impressions from objects situated in the direction of the axis of the tube. The rays traversing adjacent corneules are prevented from mixing themselves with those which are proper to each tube by the interposition of the black pigment, which completely surrounds the transparent cylinders, and intercepts all lateral or scattered light. Thus has nature supplied the want of mobility in the eyes of insects, by the vast multiplication of their number, and by providing, as it were, a separate eye for each separate point which was to be viewed; and thus has she realized the hypothetical arrangement, which suggested itself in the outset of our inquiries, while examining all the possible modes of effecting this object.

This mode of vision is probably assisted by the converging powers of each corneule, although in parts which are so minute it is hardly possible to form an accurate estimate of these powers by direct experiment. In corroboration of this view I am fortunately enabled to cite a valuable observation of the late Dr. Wollaston, relative to the eye of the *Astacus fluviatilis*, or cray-fish, where the length of each component tube is short, compared with that of the Libellula. On measuring accurately the focal distance of one of the corneules, Dr. Wollaston ascertained that it corresponds with

filaments (F) of the optic nerve, in their progress inwards, as passing through a second membrane (K, Fig. 428,) which he denominates the *common choroid*, and afterwards uniting to form an expanded layer, or more *general retina* (R,) whence proceed a small number of short but thick nervous columns (N,) still converging towards the large central ganglion (O,) in which they terminate. The use he ascribes to this second choroid is to intercept the light, which, in so diminutive an organ, might otherwise penetrate to the general retina, and produce confusion, or injurious irritation. The colour of the pigment is not always black, but often has a bluish tint: in the common fly, it is of a bright scarlet hue, resembling blood. In nocturnal insects the transverse layer of pigment between the corneule and the vitreous humour is absent.

great exactness to the length of the tube attached to it; so that an image of an exernal object is formed precisely at the point where the retina is placed to receive it.*

Little is known of the respective functions of these two kinds of eyes, the simple and the compound, both of which are generally possessed by the higher orders of winged insects. From the circumstance that the compound eyes are not developed before the insect acquires the power of flight, it has been inferred that they are more particularly adapted to the vision of distant objects; but it must be confessed that the experiments made on this subject have not, hitherto, led to any conclusive results. Dugès found, in his trials, that after the stemmata had been covered, vision remained apparently as perfect as before, while, on the other hand, when insects were deprived of the use of the compound eyes, and saw only with the stemmata, they seemed to be capable of distinguishing nothing but the mere presence or absence of light. Others have reported, that if the stemmata be covered with an opaque varnish, the insect loses the power of guiding its flight, and strikes against walls or other obstacles; whereas, if the compound eyes be covered while the stemmata remain free, the insect generally flies away, rising perpendicularly in the air, and continuing its vertical ascent as long as it can be followed by the observer. If all the eyes of an insect be covered, it will seldom make any attempt whatsoever to fly.

The eyes of insects, whether simple or compound, are immoveably fixed in their situations; but the compound eyes of the higher orders of the class Crustacea, are placed at the ends of moveable pedicles, so as to admit of being turned at pleasure towards the objects to be viewed.† This, how-

* This interesting fact was communicated to me by Captain Kater, who, together with Mr. Children, assisted Dr. Wollaston in this examination.

† Latreille describes a species of Crab, found on the shores of the Mediterranean, having its eyes supported on a long jointed-tube, consisting of two articulations, which enables the animal to move them in various directions, like the arms of a telegraph.

ever, is not the case with the *Entromostraca*, comprising the various species of *Monoculi*, in which the two eyes are brought so close to one another, as apparently to constitute a single organ, corresponding in its structure to the fourth class of eyes already enumerated; that is, the separate lenses it contains have a general envelope of a transparent membrane, or cornea. Muscles are provided for moving the eye in its socket; so that we have here indications of an approach to the structure of the eye which prevails in the higher classes of animals. There is, however, a still nearer approximation to the latter in the eye of the Cephalopoda; for *Sepiæ* differ from all the tribes belonging to the inferior orders of mollusca in having large and efficient eyes, containing a hemispherical vitreous humour, placed immediately before a concave retina, and receiving in front a large and highly convex crystalline lens, which is soft at its exterior, but rapidly increases in density, and contains a nucleus of great hardness: there is also a pigmentum nigrum, and a distinct iris, with a kidney-shaped pupil. This eye is remarkable for the total absence of a cornea; the integuments of the head being continued over the iris, and reflected over the edges of the pupil, giving a covering to the external surface of the lens: there is, of course, no chamber for containing an aqueous humour. The globe of the eye is nearly spherical, but the sclerotica is double, leaving, at the posterior part, between its two portions, a considerable space, occupied by the large ganglion of the optic nerve, with its numerous filaments, which are imbedded in a soft glandular substance.*

The eyes of Fishes differ from those of sepiæ principally in the addition of a distinct cornea, exterior to the lens and iris, but having only a slight degree of convexity. This, indeed, is the case with all aquatic animals; for, since the difference of density between the cornea and the external medium is but small, the refractive power of any cornea,

* See Cuvier, sur les Mollusques; Mémoir sur le Poulpe, p. 37. In the *Octopus* there are folds of the skin, which appear to be rudiments of eye-lids.

however convex, would be inconsiderable; and the chief agent for performing the requisite refraction of the rays is the crystalline lens. We, accordingly, in general, find the cornea nearly flat, and the globe of the eye approaching in shape to a hemisphere; while the lens itself is nearly spherical, and of great density. These circumstances are shown in the section of the eye of the *Perch*, Fig. 430.* The flatness of the cornea leaves scarcely any space for aqueous humour, and but little for the motions of the iris.

The surface of the eye in fishes, being continually washed by the water in which it is immersed, requires no provision of a secreted fluid for that purpose; and there are consequently neither lacrymal apparatus, nor proper eye-lids; the integuments supplying only a thin transparent membrane, which passes over and protects the cornea, serving the office of a conjunctiva. The eye retains its form by the support it receives from the sclerotic coat, which is of extraordinary thickness and density. In the *Shark* and the *Skate*, the eye is supported from the bottom of the orbit, by a cartilaginous pedicle, which enables it to turn as on a pivot, or lever.

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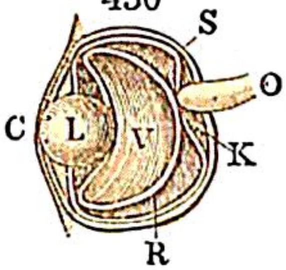

Sir David Brewster has recently made an interesting analysis of the structure of the crystalline lens of the *Cod*, to which he was led by noticing some remarkable optical appearances presented by thin layers of this substance when transmitting polarized light. He found that the hard central portion is composed of a succession of concentric, and perfectly transparent, spheroidal laminæ, the surfaces of which, though apparently smooth, have the same kind of iridescence as mother-of-pearl, and arising from the same cause; namely, the occurrence of regularly arranged lines,

* In this figure, as in the others, C is the cornea; L, the lens; V, the vitreous humour; R, the retina; O, the optic nerve; and S, the sclerotica. There is also found in the eyes of most fishes an organ, lodged in the space K, termed the *Choroid gland*, which envelops the optic nerve, is shaped like a horse-shoe, is of a deep red colour, and highly vascular; its use is quite unknown.

or *striæ*.* These lines, which mark the edges of the separate fibres, composing each laminæ, converge like meridians from the equator to the two poles of the spheroid, as is shown in Fig. 431. The fibres themselves are not cylindri-

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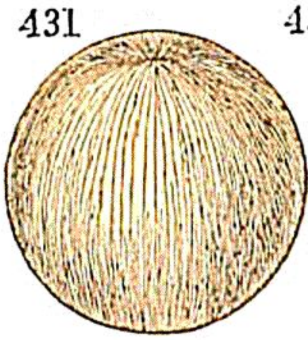

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cal, but flat; and they taper at each end as they approach the points of convergence. The breadth of the fibres in the most external layer, at the equator, is about the 5,500th part of an inch. The observation of another optical phenomenon, of a still more delicate kind, led Sir David Brewster to the farther discovery of the curious mode in which, (as is represented in Fig. 432,) the fibres are locked together at their edges by a series of teeth, resembling those of rack-work. He found the number of teeth in each fibre to be 12,500; and, as the whole lens contains about 5,000,000 fibres, the total number of these minute teeth amounts to 62,500,000,000.†

Some fishes, which frequent the depths of the ocean, being found at between three and four hundred fathoms below the surface, to which it is impossible that any sensible quantity of the light of day can penetrate, have, like nocturnal quadrupeds, very large eyes.‡ In a few species, which

* See vol. i. p. 169.

† As far as his observations have extended, this denticulated structure exists in the lenses of all kinds of fishes, and likewise in those of birds. He has also met with it in two species of *Lizards*, and in the *Ornithorhyncus;* but he has not been able to find it in any of the *Mammalia*, not even in the *Cetacea*. (Phil. Trans. for 1833, p. 323.)

‡ See "Observations sur les Poissons recueillis dans un Voyage aux Iles Baléares et Pythiuses. Par M. Delaroche."

dwell in the muddy banks of rivers, as the *Cæcilia*, and *Muræna cæca*, or blind eel, the eyes are quite rudimental, and often nearly imperceptible; and in the *Gastrobranchus*, De Blainville states that it is impossible, even by the most careful dissection, to discover the least trace of eyes.

Reptiles, being destined to reside in air as well as in water, have eyes accommodated to these variable circumstances. By the protrusion of the cornea, and the addition of an aqueous humour, they approach nearer to the spherical form than the eyes of fishes; and the lens has a smaller refractive power, because the principal refraction is now performed by the cornea. Rudiments of eye-lids are met with in the *Salamander*, but they are not of sufficient extent to cover the whole surface of the eyes. In some serpents, the integuments pass over the globe of the eye, forming a transparent conjunctiva, or external cornea, behind which the eye-ball has free motion. This membrane is shed, along with the cuticle, every time that the serpent is moulting; and at these epochs, while the cornea is preparing to detach itself, air insinuates itself underneath the external membrane, and renders it opaque; so that until this operation is completed, and an entire separation effected, the serpent is rendered blind. Serpents have no proper eyelids; but the cornea is covered by a transparent integument, which does not adhere to it.* Lizards have usually a single perforated eye-lid, which, when closed by its orbicular muscle, exhibits merely a horizontal slit. There is also a small internal fold, forming the rudiment of a third eye-lid. The *Chameleon* has remarkably projecting eyes, to which the light is admitted through a very minute perforation in

* It was the general opinion, until very lately, that serpents are unprovided with any lacrymal apparatus; but a small lacrymal passage has been recently discovered by Cloquet, leading from the space in the inner corner of the eye, between the transparent integument and the cornea. This lacrymal canal opens into the nasal cavity in venomous snakes, and into the mouth in those that are not venomous.

the skin constituting the outer eye-lid. This animal has the power of turning each eye, independently of the other, in a great variety of directions.

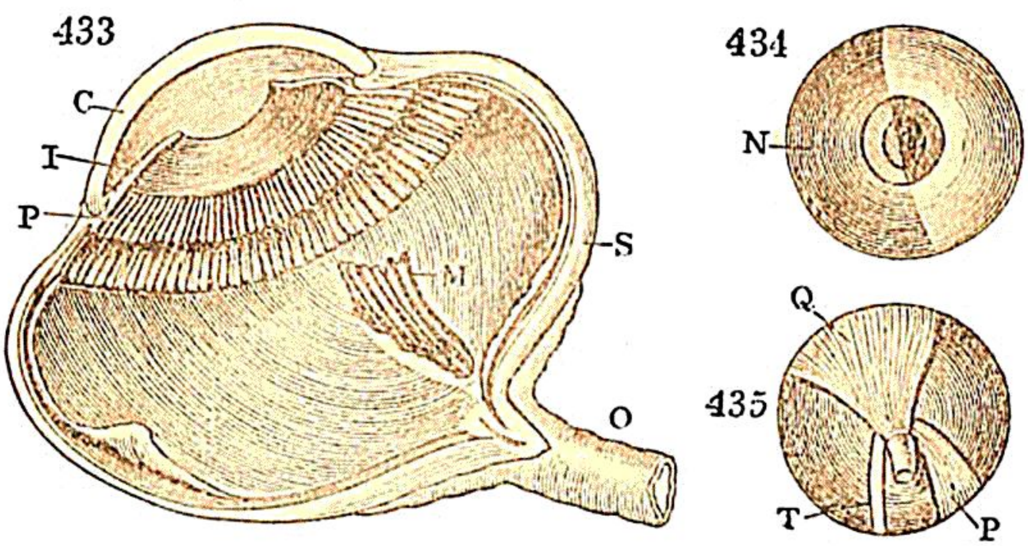
The eyes of Tortoises exhibit an approach to those of birds: they are furnished with large lacrymal glands, and with a very moveable *membrana nictitans* or third eye-lid.

Birds present a still farther development of all these parts: their eyes are of great size compared with the head, as may be seen from the large portion of the skull which is occupied on each side by the orbits. The chief peculiarities of the internal structure of these organs are apparently designed to accommodate them to vision through a very rare medium, and to procure their ready adjustment to objects situated at very different distances. The form of the eye appears calculated to serve both these purposes; for the great prominence of its anterior portion, which has often the shape of a short cone, or cylinder, prefixed to the front of a hemispherical globe, and which is terminated by a very convex cornea, affords space for a larger quantity of aqueous humour, and also for the removal of the lens to a greater distance from the retina; whereby the vision of near objects is facilitated, while at the same time the refracting powers are susceptible of great variation.

For the purpose of preserving the hemispherical form of the sclerotica, this membrane in birds is strengthened by a circle of bony plates, which occupy the fore-part, and are lodged between the two layers of which it consists. These plates vary in number from fifteen to twenty, and they lie close together, their edges successively overlapping each other. There is manifest design in this arrangement; for it is clear that a ring formed of a number of separate plates is better fitted to resist fracture than an entire bony circle of the same thickness.

There is a dark-coloured membrane, called the *Marsupium*, situated in the vitreous humour, the use of which is unknown, though it appears to be of some importance, as it is found in almost every bird having extensive powers of vision.* The comparative anatomy of the eye offers, indeed, a great number of special structures of which we do not understand the design, and which I have therefore purposely omitted to notice, as being foreign to the object of this treatise.

In most birds the *membrana nictitans*, or third eye-lid, is of considerable size, and consists of a semi-transparent fold of the conjunctiva, lying, when not used, in the inner corner of the eye, with its loose edge nearly vertical: it is represented at N, Fig. 434, covering half the surface of the eye: its motion, like that of a curtain, is horizontal, and is effected by two muscles: the first of which, seen at Q, in Fig. 435, is called, from its shape, the *quadratus*, and arises from the upper and back part of the sclerotica: its fibres descending in a parallel course towards the optic nerve, where



they terminate, by a semicircular edge, in a tubular tendon. This tendon has no particular attachment, but is employed for the purpose of serving as a loop for the passage of the long tendon of the second muscle, (P,) which is called the *pyramidalis*, and which arises from the lower and back part

* It is shown at M, Fig. 433, which is a magnified section of the eye of a Goose. C is the cornea; I, the iris; P, the ciliary processes, S, the sclerotic coat, and O, the optic nerve.

of the sclerotica, its tendon (T,) after passing through the channel above described, which has the effect of a pulley, is conducted through a circular sheath, furnished by the sclerotica to the under part of the eye, and is inserted into the lower portion of the loose edge of the nictitating membrane. By the united action of these two muscles, the former of which serves merely to guide the tendon of the latter, and increase the velocity of its action, the membrane is rapidly drawn over the front of the globe. Its return to its former position is effected simply by its own elasticity, which is sufficient to bring it back to the inner corner of the eye. If the membrane itself had been furnished with muscular fibres for effecting this motion, they would have interfered with its use by obstructing the transmission of light.

The eyes of quadrupeds agree in their general structure with those of man. In almost all the inferior tribes they are placed laterally in the head, each having independent fields of vision, and the two together commanding an extensive portion of the whole sphere. This is the case very generally among fishes, reptiles, and birds. Some exceptions, indeed, occur in particular tribes of the first of these classes, as in the *Uranoscopus*, where the eyes are directed immediately upwards; in the *Ray* and the *Callionymus*, where their direction is oblique; and in the *Pleuronectes*, where there is a remarkable want of symmetry between the right and left sides of the body, and where both eyes, as well as the mouth, are apparently situated on one side. Among birds, it is only in the tribe of Owls, which are nocturnal and predaceous, that we find both eyes placed in front of the head. In the lower quadrupeds, the eyes are situated laterally, so that the optic axes form a very obtuse angle with each other. As we ascend towards the quadrumana we find this angle becoming smaller, till at length the approximation of the fields of view of the two eyes is such as to admit of their being both directed to the same object at the same time. In the human species the axes of the two orbits approach nearer to parallelism than in any of the other mammalia; and the fields of vision of both eyes coincide nearly in their whole extent. This is probably a circumstance of considerable importance with regard to our acquisition of correct perceptions by this sense.

In the magnitude of the organ compared with that of the body, we may occasionally observe some relation to the character of the animal and the nature of its pursuits. Herbivorous animals, and especially those whose bulk is great, as the *Elephant*, the *Rhinoceros*, and the *Hippopotamus*, have comparatively small eyes; for that of the elephant does not exceed two inches in diameter. The eye of the *Whale* is not much more than the 200th part of the length of the body. In the purely carnivorous tribes, which are actively engaged in the chase of living prey, the organ of vision is large, and occupies a considerable portion of the head; the orbit is much developed, and encroaches on the bones of the face; while, at the same time, the bony partition separating the globe of the eye from the temporal muscle is supplied by ligament alone: so that when that muscle is in strong action, the eye is pressed outwards, giving a peculiar ferocity of expression to the countenance.

While nature has thus bestowed great acuteness of sight on pursuing animals, she has, on the other hand, been no less careful to arm those which are the objects of pursuit, with powers of vision, enabling them to perceive their enemies from afar, and avoid the impending danger. Thus, large eyes are bestowed on the *Rodentia* and the *Ruminantia*. Those tribes which pursue their prey by night, or in the dusk of the evening, as for example the *Lemur* and the *Cat*, are furnished with large eyes. Bats, however, form an exception to this rule, their eyes being comparatively small; but a compensation has been afforded them in the superior acuteness of their other senses. In many quadrupeds a portion of the choroid coat is highly glistening, and reflects a great quantity of coloured light: the object of this structure, which is termed the *Tapetum*, is not very apparent.

Among the lesser quadrupeds which burrow in the ground, we find many whose eyes are extremely minute, so much so, indeed, as to be scarcely serviceable as visual organs. The eye of the *Sorex*, or shrew mouse, is very small, and surrounded by thick hair, which completely obstructs vision, and requires to be removed by the action of the subcutaneous muscles, in order to enable the animal to derive any advantage from its eyes. These organs in the *Mole* are still more remarkably deficient in their development, not being larger than the head of a pin, and consequently not easily discovered.* It is therefore probable that this animal trusts chiefly to its sense of hearing, which is remarkably acute, for intimations of the approach of danger, especially as, in its subterranean retreats, the vibrations of the solid earth are readily transmitted to its ears. The *Mus typhlus*, or blind rat of Linnæus; (the *Zemni* of Pallas,) which is an inhabitant of the western parts of Asia, cannot be supposed to possess even the small degree of vision of the mole; for no external organ of this sense has been detected in any part of that animal. The whole side of the head is covered with a continuous integument of uniform thickness, and equally overspread with a thick velvety hair. It is only after removing the skin that a black spot is discovered on each side, of exceedingly small size, and apparently the mere imperfect rudiment of an eye, and, as far as we can perceive, incapable of exercising any of the functions of vision.

Those mammalia, whose habits are aquatic, having the eye frequently immersed in a dense medium, require a special provision for accommodating the refractive power of that organ to this variation of circumstances. Accordingly, it is found that in the *Seal*, and other amphibious tribes, the structure of the eye approaches to that of fishes, the lens be-

* Magendie asserts that the mole has no optic nerve; but G. St. Hilaire and Carus recognise the existence of a very slender nervous filament, arising from the brain, and distributed to the eye of that animal.

ing denser and more convex than usual, the cornea thin and yielding, and both the anterior and posterior segments of the sclerotic thick and firm; but the middle circle is very thin and flexible, admitting of the ready separation or approximating of the other portions, so as to elongate or contract the axis of the eye; just as a telescope can be drawn out or shortened, in order to adapt it to the distance of the object to be viewed. The whole eye-ball is surrounded by strong muscles which are capable of effecting these requisite changes of distance between the cornea and the retina. The *Dolphin*, which lives more constantly in the water, has an eye still more nearly approaching in its structure to that of fishes; the crystalline lens being nearly spherical, and the globe of the eye furnished with strong and numerous muscles. In birds which frequently plunge their heads under water the crystalline lens is more convex than in other tribes; and the same is true, also, of aquatic reptiles.

CHAPTER VII.

PERCEPTION.

The object of nature in establishing the organizations we have been reviewing is to produce certain modified impressions on the extremities of particular nervous filaments provided to receive them; but these impressions constitute only the commencement of the series of corporeal changes which terminate in sensation; for they have to be conveyed along the course of the nerves to the brain, or central organ of the nervous system,* where, again, some physical change must take place, before the resulting affection of the mind can be produced. The particular part of the brain, where this last physical change, immediately preceding the mental change, takes place, is termed the *Sensorium*. Abundant proofs exist that all the physical changes here referred to really occur, and, also, that they occur in this order of succession; for they are invariably found to be dependent on the healthy state, not only of the nerve, but, also, of the brain: thus, the destruction, or even compression of the nerve, in any part of its course between the external organ and the sensorium, totally prevents sensation; and the like result ensues from even the slightest pressure made on the sensorium itself.

Although the corporeal or physical change taking place in the sensorium, and the mental affection we term sensation, are linked together by some inscrutable bond of connexion,

* It is usual to designate the end of the nerve which is next to the sensorium, as the origin of that nerve; whereas, it should more properly be regarded as its termination; for the series of changes which end in sensation commence at the organ of sense, and are thence propagated along the nerve to the sensorium.

they are, in their nature, as perfectly distinct as the subjects in which they occur; that is, as *mind* is distinct from *matter;* and they cannot, therefore, be conceived by us as having the slightest resemblance the one to the other. Yet sensations invariably suggest to the mind ideas, not only of the existence of an external agent as producing them, but also of various qualities and attributes belonging to these agents; and the term *Perception* expresses the belief, or rather the irresistible conviction, thus forced upon us, of the real existence of these external agents, which we conceive as constituting the material world.

Various questions here present themselves concerning the origin, the formation, and the laws of our perceptions. This vast field of curious but difficult inquiry, situated on the confines of the two great departments of human knowledge, (of which the one relates to the phenomena of matter, and the other to those of mind,) requires for its successful cultivation the combined efforts of the physiologist and the metaphysician. For although our sensations are purely mental affections, yet inasmuch as they are immediately dependent on physical causes, they are regulated by the physical laws of the living frame; whereas the perceptions derived from these sensations, being the results of intellectual processes, are subject rather to the laws which regulate mental than physical phenomena. It is certain, from innumerable facts, that in the present state of our existence, the operations of the mind are conducted by the instrumentality of our bodily organs; and that unless the brain be in a healthy condition, these operations become disordered, or altogether cease. As the eye and the ear are the instruments by which we see and hear, so the brain is the material instrument by which we retrace and combine ideas, and by which we remember, we reason, we invent. Sudden pressure on this organ, as in a stroke of apoplexy, puts a total stop to all these operations of the mind. If the pressure be of a nature to admit of remedy, and has not injured the texture of the brain, recovery may take place; and immediately on the return of consciousness, the person awakes as from a dream, having no sense of the time which has elapsed since the moment of the attack. All causes which disturb the healthy condition of the brain, such as alcohol, opium, and other narcotic drugs, or which disorder more especially the circulation in that organ, such as those inducing fever, or inflammation, produce corresponding derangements of the intellectual powers; modifying the laws of the association of ideas, introducing confusion in the perceptions, irregularity in the trains of thought, or incapacity of reasoning, and leading to the infinitely diversified forms of mental hallucination, delirium, or insanity. Even the strongest minds are subject to vicissitudes arising from slighter causes, which affect the general tone of the nervous system. Vain, indeed, was the boast of the ancient Stoics that the human mind is independent of the body, and impenetrable to external influences. No mortal man, whatever may be the vigour of his intellect, or the energy of his application, can withstand the influence of impressions on his external senses; for, if sufficiently reiterated or intense, they will always have power, if not to engross his whole attention, at least to interrupt the current of his thoughts, and direct them into other channels. Nor is it necessary for producing this effect that cannon should thunder in his ears; the mere rattling of a window, or the creaking of a hinge will often be sufficient to disturb his philosophical meditations, and dissever the whole chain of his ideas. "Marvel not," says Pascal, "that this profound statesman is just now incapable of reasoning justly; for, behold, a fly is buzzing round his head. If you wish to restore to him the power of correct thinking, and of distinguishing truth from falsehood, you must first chase away the insect, holding in thraldom that exalted reason, and that gigantic intellect, which govern empires, and decide the destinies of mankind."

Although we must necessarily infer, from the evidence furnished by experience, that some physical changes in the brain accompany the mental processes of thought, we are in utter ignorance of the nature of those actions; and all our knowledge on this subject is limited to the changes which we are conscious are going on in the mind. It is to these mental changes, therefore, that our attention is now to be directed.

In experiencing mere sensations, whatever be their assemblage or order of succession, the mind is wholly passive: on the other hand, the mind is active on all occasions when we combine into one idea sensations of different kinds, (such as those which are derived from each separate sense,) when we compare sensations or ideas with one another, when we analyze a compound idea, and unite its elements in an order or mode of combination different from that in which they were originally presented. Many of these active operations of mind are implied in the process of perception; for although it might be supposed that the diversity in the nature of our sensations would sufficiently indicate to us a corresponding variety in the qualities of the material agents, which produce their impressions on our senses, yet these very qualities, nay, even the existence of the objects themselves, are merely inferences deduced by our reasoning powers, and not the immediate effects of those impressions on the mind. We talk, for instance, of seeing a distant body; yet the immediate object of our perception can only be the light, which has produced that particular impression on our retina; whence we infer, by a mental process, the existence, the position, and the magnitude of that body. When we hear a distant sound, the immediate object of our perception is neither the sounding body whence it emanates, nor the successive undulations of the medium conveying the effect to our ear; but it is the peculiar impression made by the vibrating particles of the fluid, which are in direct contact with the auditory nerve. It is not difficult to prove that the objects of perception are mere creations of the mind, suggested, probably instinctively, by the accompanying sensations, but having no real resemblance or correspondence either with the impressions themselves, or with the agencies which produce them; for many are the instances in which our actual perceptions are widely different from the truth, and have no external prototype in nature. In the absence of light, any mechanical pressure, suddenly applied to the eye, excites, by its effect on the retina, the sensation of vivid light. That this sensation is present in the mind we are certain, because we are conscious of its existence: here there can be no fallacy. But the perception of light, as a cause of this sensation, being inseparably associated with such sensation, and wholly dependent on it, and corresponding in all respects, both as to its duration and intensity, with the same circumstances in the sensation, we cannot avoid having the *perception* as well as the *sensation* of light: yet it is certain that no light has acted. The error, then, attaches to the perception; and its source is to be traced to the mental process by which perception is derived from sensation.

Many other examples might be given of fallacious perceptions, arising from impressions made in an unusual manner on the nerves of the senses. One of the most remarkable is the appearance of a flash of light from the transmission of the galvanic influence through the facial nerves. If a piece of silver, or of gold, be passed as high as possible between the upper lip and the gums, while at the same time a plate of zinc is laid on the tongue, or applied to the inside of the cheeks; and if a communication be then made between the two metals, either by bringing them into direct contact, or by means of a wire touching both of them at the same time, a flash of light is seen by the person who is the subject of the experiment. This appearance is the effect of an impression made either on the retina, or on the optic nerve, and is analogous to that occasioned by a mechanical impulse, such as a blow directed to the same part of the nervous system, both being phenomena totally independent of the presence of light. A similar fallacy occurs in the perception of taste, which arises in the well known experiment of placing a piece of zinc and another of silver, the one on the upper and the other on the under surface of the tongue, and making them communicate, when a pungent and disagreeable metallic taste is instantly perceived: this happens because the nerves of the tongue, being acted upon by the galvanism thus excited, communicate the same sensation as that which would be occasioned by the actual application of sapid bodies to that organ. Thus, it appears that causes which are very different in their nature, may, by acting on the same nerves, produce the very same sensation; and it follows, therefore, that our sensations cannot be depended upon as being always exactly correspondent with the qualities of the external agent which excites them.

Evidence to the same effect may also be gathered from the consideration of the narrowness of those limits within which all our senses are restricted. It requires a certain intensity in the agent, whether it be light, or sound, or chemical substances applied to the senses of smell or taste, in order to produce the very lowest degree of sensation. On the other hand, when their intensity exceeds a certain limit, the nature of the sensation changes, and becomes one of pain. Of the sensations commonly referred to the sense of touch, there are many which convey no perception of the cause producing them. Thus, a slighter impression than that which gives the feeling of resistance produces the sensation of itching, which is totally different in its kind. The sensation of cold is equally positive with that of warmth, and differs from it, not in degree merely, but in species; although we know that it is only in its degree that the external cause of each of these sensations differs.

The only distinct notions we are capable of forming respecting *Matter*, are that it consists of certain powers of attraction and repulsion, occupying certain portions of space, and capable of moving in space; and that its parts thereby assume different relative positions or configurations. But of *mind*, our knowledge is more extensive and more precise, because we are conscious of its existence, and of many of its operations, which are comprised in the general term *thought*. To assert that thought can be a property of matter, is to extend the meaning of the term matter to that with which we cannot perceive it has any relation. All that we know of matter has regard to space: nothing that we know of the properties and affections of mind has any relation whatsoever to space.

A similar incongruity is contained in the proposition that thought is a *function* of the brain. It is not the brain which thinks, any more than it is the eye which sees, though each of these material organs is necessary for the production of their respective effects. That which sees and which thinks is exclusively the mind; although it is by the instrumentality of its bodily organs that these changes take place. Attention to this fundamental distinction, which, although obvious when explicitly pointed out, is often lost sight of in ordinary discourse, will furnish a key to the solution of many questions relating to perception, which have been considered as difficult and embarrassing.

The sensations derived from the different senses have no resemblance to one another, and have, indeed, no property in common, except that they are felt by the same percipient being. A colour has no sort of resemblance to a sound; nor have either of these any similarity to an odour, or a taste, or to the sensations of heat, or cold. But the mind, which receives these incongruous elements, has the power of giving them, as it were, cohesion, of comparing them with one another, of uniting them into combinations, and of forming them into ideas of external objects. All that nature presents is an infinite number of particles, scattered in different parts of space; but out of these the mind forms individual groups, to which she gives a unity of her own creation.

All our notions of material bodies involve that of space; and we derive this fundamental idea from the peculiar sensations which attend the actions of our voluntary muscles. These actions first give us the idea of our own body, of its various parts, and of their figure and movements; and next teach us the position, distances, magnitudes, and figures of adjacent objects. Combined with these ideas are the more immediate perceptions of touch, arising from contact with the skin, and especially with the fingers. All these perceptions, variously modified, make us acquainted with those mechanical properties of bodies, which have been regarded by many as primary or essential qualities. The perceptions derived from the other senses can only add to the former the ideas of partial, or secondary qualities, such as temperature, the peculiar actions which produce taste and smell, the sounds conveyed from certain bodies, and, lastly, their visible appearances.

The picture formed on the retina by the refracting power of the humours of the eye, is the source of all the perceptions which belong to the sense of vision; but the visible appearances which these pictures immediately suggest, when taken by themselves, could have given us no notion of the situation, distances, or magnitudes of the objects they represent; and it is altogether from the experience acquired by the exercise of other senses that we learn the relation which these appearances have with those objects. In process of time the former become the signs and symbols of the latter; while abstractedly, and without such reference, they have no meaning. The knowledge of these relations is acquired by a process exactly analogous to that by which we learn a new language. On hearing a certain sound in constant conjunction with a certain idea, the two become inseparably associated together in our minds; so that on hearing the name, the corresponding idea immediately presents itself. In like manner, the visible appearance of an object is the sign, which instantly impresses us with ideas of the presence, distance, situation, form, and dimensions of the body, that gave rise to it. This association is, in man at least, not original, but acquired. The objects of sight and touch, as Bishop Berkeley has justly observed, constitute two worlds, which, although they have a very important correspondence and connexion, yet bear no sort of resemblance to one another. The tangible world has three dimensions, namely, length, breadth, and thickness; the visible world only two, namely, length and breadth. The objects of sight constitute a kind of language, which Nature addresses to our eyes, and by which she conveys information most important to our welfare. As, in any language, the words or sounds bear no resemblance to the things they denote, so in this particular language the visible objects bear no sort of resemblence to the tangible objects they represent.

The theory of Berkeley received complete confirmation by the circumstances attending the well known case, described by Cheselden, of a boy, who, from being blind from birth, suddenly acquired, at the age of twelve, the power of seeing, by the removal of a cataract. He at first imagined that all the objects he saw touched his eyes, as what he felt did his skin; and he was unable either to estimate distances by the sight alone, or even to distinguish one object from another, until he had compared the visual with what has been called the *tactual* impression.

This theory also affords a satisfactory solution of a question which has frequently been supposed to involve considerable difficulty; namely, how it happens that we see objects in their true situation, when their images on the retina, by which we see them, are inverted. To expect that the impression from an inverted image on the retina should produce the perception of a similar position in the object viewed, is to commit the error of mistaking these images for the real objects of perception, whereas they are only the means which suggest the true perceptions. It is not the eye which sees; it is the mind. The analogy which the optical part of the eye bears to a camera obscura has perhaps contributed to the fallacy in question; for, in using that instrument, we really contemplate the image which is received on the paper, and reflected from it to our eyes. But in our own vision nothing of this kind takes place. Far from there being any contemplation by the mind of the image on the retina, we are utterly unconscious that such an image exists, and still less can we be sensible of the position of the image with respect to the object. All that we can distinguish as to the locality of the visual appearance which an object produces, is that this appearance occupies a certain place in the field of vision; and we are taught, by the experience of our other senses, that this is a sign of the existence of the external object in a particular direction with reference to our own body. It is not until long after this association has been established, that we learn, by deduction from scientific principles, that the part of the retina, on which the impression causing this appearance is made, is on the side opposite to that of the object itself; and also that the image of a straight object is curved as well as inverted. But this subsequent information can never interfere with our habitual, and perhaps instinctive reference of the appearance resulting from an impression made upon the upper part of the retina, to an object situated below us, and *vice versâ*. Hence we at once refer impressions made on any particular part of the retina to a cause proceeding from the opposite side. Thus, if we press the eye-ball with the finger applied at the outer corner of the orbit, the luminous appearance excited by the pressure is immediately referred to the opposite or inner side of the eye.

If we place a card perpendicularly between the two eyes, and close to the face, the card will appear double, because, although each surface is seen by the eye which is adjacent to it, in the direction in which it really is with regard to that eye, yet, being out of the limits of distinct vision, it is referred to a much greater distance than its real situation; and consequently, the two sides of the object appear separated by a wide interval, and as if they belonged to two different objects. Many other examples might be given of similar fallacies in our visual perceptions.

All impressions made on the nerves of sensation have a definite duration, and continue for a certain interval of time after the action of the external agent has ceased. The operation of this law is most conspicuous in those cases where the presence or absence of the agent can readily be determined. Thus, we retain the sensation of a sound for some time after the vibrations of the external medium have ceased; as is shown by the sensation of a musical note being the result of the regular succession of aerial undulations, when the impression made by each continues during the whole interval between two consecutive vibrations. Whether light be caused by the emission of material particles, or the undulations of an ethereal fluid, its impulses on the retina are unquestionably consecutive, like those of sound, but being repeated at still shorter intervals, they give rise to a continuous impression. A familiar instance of the same principle occurs in the appearance of an entire luminous circle, from the rapid whirling round of a piece of lighted charcoal; for the part of the retina which receives the brilliant image of the burning charcoal, retains the impression with nearly the same intensity during the entire revolution of the light, when the same impression is renewed. For the same reason a rocket, or a fiery meteor, shooting across the sky in the night, appears to leave behind it a long luminous train. The exact time, during which these impressions continue, after the exciting cause has been withdrawn, has been variously estimated by different experimentalists, and is very much influenced, indeed, by the intensity of the impression.*

* Many curious visual illusions may be traced to the operation of this principle. One of the most remarkable is the curved appearance of the spokes of a carriage wheel rolling on the ground, when viewed through the intervals between vertical parallel bars, such as those of a palisade, or Venetian window-blind. On studying the circumstances of this phenomenon, I found that it was the necessary result of the traces left on the retina by the parts of each spoke which became in succession visible through the apertures, and assumed the curved appearances in question. A paper, in which I gave an account of the details of these observations, and of the theory by which I explained them, was presented to the Royal Society, and published in the Philosophical Transactions, for 1825, p. 131. About three years ago, Mr. Faraday prosecuted the subject with the usual success which attends all his philosophical researches, and devised a great number of interesting experiments on the appearances resulting from combinations of revolving wheels; the details of which are given in a paper contained in the first volume of the Journal of the Royal Institution of Great Britain, p. 205. This again directed my attention to the subject, and led me to the invention of the instrument which has since been introduced into notice under the name of the Phantas-

When the impressions are very vivid, another phenomenon often takes place; namely, their subsequent recurrence, after a certain interval, during which they are not felt, and quite independently of any renewed application of the cause which had originally excited them. If, for example, we look steadfastly at the sun for a second or two, and then immediately close our eyes, the image or *spectrum* of the sun remains for a long time present to the mind, as if its light were still acting on the retina. It then gradually fades and disappears; but if we continue to keep the eyes shut, the same impression will, after a certain time, recur, and again vanish; and this phenomenon will be repeated at intervals, the sensation becoming fainter at each renewal. It is probable that these reappearances of the image, after the light which produced the original impression has been withdrawn, are occasioned by spontaneous affections of the retina itself, which are conveyed to the sensorium. In other cases, where the impressions are less strong, the physical changes producing these spectra are perhaps confined to the sensorium. These spectral appearances generally undergo various changes of colour, assuming first a yellow tint, passing then to a green, and lastly becoming blue, before they finally disappear.

Another general law of sensation is, that all impressions made on the nerves of sense tend to exhaust their sensibility, so that the continued or renewed action of the same external cause produces a less effect than at first: while, on the other hand, the absence or diminution of the usual excitement leads to a gradual increase of sensibility, so that the subsequent application of an exciting cause produces more than the usual effect. One of the most obvious exemplifications of this law presents itself in the case of the sensations of temperature. The very same body may appear warm to

mascope or Phenakisticope. I constructed several of these at that period, (in the spring of 1831) which I showed to many of my friends; but in consequence of occupations and cares of a more serious kind, I did not publish any account of this invention, which was last year reproduced on the continent.

the touch at one time, and cold at another, (although its real temperature has not varied,) according to the state of the organ induced by previous impressions: and a very different judgment will be formed of its temperature, when felt by each hand in succession, if the one has immediately before been exposed to cold, while the other has retained its natural warmth. Similar phenomena may be observed with regard to all the other senses: thus, the flavour of odorous, as well as sapid bodies, depends much on the previous state of the organ by which they are perceived; any strong impression of taste made on the nerves of the tongue, rendering them, for some time, nearly insensible to weaker tastes. Sounds, which make a powerful impression on the auditory nerves, will, in like manner, occasion temporary deafness with regard to faint sounds. The converse of this is observed when hearing has been suddenly restored in deaf persons, by the operation of perforating the ear-drum.* The sensibility of the auditory nerves, which had not been accessible to impressions of sound, is found to be increased to a morbid degree. This was remarkably exemplified in the case of a gentleman, who, for several years, had been very deaf, in consequence of the obliteration of the Eustachian tube, so that he could scarcely hear a person speaking in a loud voice close to his ear. As soon as the instrument which had made the perforation was withdrawn, the by-standers began to address him in a very low tone of voice, and were surprised at receiving no answer, and at his remaining immoveable in his chair, as if stunned by a violent blow. At length, he burst out into the exclamation, "For God's sake, gentlemen, refrain from crying out so terribly loud! you are giving me excessive pain by speaking to me." The surgeon,† upon this, retired across the room; unfortunately, however, the creaking of his boots caused the gentleman to start up in an agony from his chair, at the same time applying his hand instinctively to cover his ear; but in doing this,

* See the note in p. 307 of this volume.

† M. Maunoir, of Geneva, on whose authority I have given this account.

the sound of his fingers coming in contact with his head was a fresh source of pain, producing an effect similar to that of a pistol suddenly fired close to him. For a long time after, when spoken to, even in the lowest whisper, he complained of the distressing loudness of the sounds; and it was several weeks before this excessive sensibility of the auditory nerves wore off: by degrees, however, they accommodated themselves to their proper function, and became adapted to the ordinary impressions of sound. Some time afterwards, this gentleman had a similar operation performed on the other ear, and with precisely the same results; the same degree of excessive sensibility to sounds was manifested on the restoration of hearing in this ear as had occurred in the first; and an equal time elapsed before it was brought into its natural state.

The most striking illustrations of the extent of this law are furnished by the sense of vision. On entering a dark chamber, after having been for some time exposed to the glare of a bright sunshine, we feel as if we were blind; for the retina, having been exhausted by the action of a strong light, is insensible to the weaker impressions which it then receives. It might be supposed that the contraction of the pupil, which takes place on exposure to a strong light, and, of course, greatly reduces the quantity admitted to the retina, is a cause adequate to account for this phenomenon: but careful observation will show that the pupil very rapidly enlarges to its full expansion when not acted upon by light: while the insensibility of the retina continues for a much longer time. It regains its usual sensibility, indeed, only by slow degrees. By remaining in the dark its sensibility is still farther increased, and a faint light will excite impressions equal to those produced in the ordinary state of the eye by a much stronger light; and while it is in this state, the sudden exposure to the light of day produces a dazzling and painful sensation.

This law of vision was usefully applied by Sir William Herschel in training his eye to the acquisition of extraordinary sensibility, for the purpose of observing very faint celestial objects. It often happened to him, when, in a fine winter's night, and in the absence of the moon, he was occupied during four, five, or six hours in taking sweeps of the heavens with his telescope, that, by excluding from the eye the light of surrounding objects, by means of a black hood, the sensibility of the retina was so much increased, that when a star of the third magnitude approached the field of view, he found it necessary immediately to withdraw his eye, in order to preserve its powers. He relates that on one occasion the appearance of Sirius announced itself in the field of the telescope like the dawn of the morning, increasing by degrees in brightness, till the star at last presented itself with all the splendour of the rising sun, obliging him quickly to retreat from the beautiful but overpowering spectacle.

The peculiar construction of the organ of vision allows of our distinguishing the effects of impressions made on particular parts of the retina from those made on the rest, and from their general effect on the whole surface. These partial variations of sensibility in the retina give rise to the phenomena of *ocular spectra*, as they are called, which were first noticed by Buffon, and afterwards more fully investigated by Dr. Robert Darwin. A white object on a dark ground, after being viewed steadfastly till the eye has become fatigued, produces, when the eye is immediately directed to another field of view, a spectrum of a darker colour than the surrounding space, in consequence of the exhaustion of that portion of the retina on which its image had been impressed. The converse takes place, when the eye, after having been steadfastly directed to a black object on a light ground, is transferred to another part of the same field; and in this case a bright spectrum of the object is seen.

It is a still more curious fact that the sensibility of the retina to any particular kind of light, may, in like manner, be increased or diminished, without any change taking place in its sensibility to other kinds of light. Hence the spectrum of a red object appears green; because the sensibility of that portion of the retina, on which the red image has been impressed, is impaired with regard to the red rays, while the yellow and the blue rays still continue to produce their usual effect; and these, by combining their influence, produce the impression of green. For a similar reason, the spectrum of a green object is red; the rays of that colour being those which alone retain their power of fully impressing the retina, previously rendered less sensible to the yellow and the blue rays composing the green light it had received from the object viewed.

The judgments we form of the colours of bodies are influenced, in a considerable degree, by the vicinity of other coloured objects, which modify the general sensibility of the retina. When a white or gray object of small dimensions, for instance, is viewed on a coloured ground, it generally appears to assume a tint of the colour which is *Complementary* to that of the ground itself.* It is the etiquette among the Chinese, in all their epistles of ceremony, to employ paper of a bright scarlet hue: and I am informed by Sir George Staunton, that for a long time after his arrival in China, the characters written on this kind of paper appeared to him to be green; and that he was afterwards much surprised at discovering that the ink employed was a pure black, without any tinge of colour, and on closer examination he found that the marks were also black. The green appearance of the letters, in this case, was an optical illusion, arising from the tendency of the retina, which had been strongly impressed with red light, to receive impressions corresponding to the complementary colour, which is green.

A philosophical history of the illusions of the senses would afford ample evidence that limits have been intentionally assigned to our powers of perception; but the subject is much

* Any two colours which, when combined together, produce white light, are said to be *complementary* to one another.

*too extensive to be treated at length in the present work.** I must content myself with remarking, that these illusions are the direct consequences of the very same laws, which, in ordinary circumstances, direct our judgment correctly, but are then acting under unusual or irregular combinations of circumstances. These illusions may be arranged under three classes, according as they are dependent on causes of a physical, physiological, or mental kind.

The first class includes those illusions in which an impression is really made on the organ of sense by an external cause, but in a way to which we have not been accustomed. To this class belong the acoustic deceptions arising from echoes, and from the art of ventriloquism; the deceptive appearances of the mirage of the desert, the looming of the horizon at sea, the *Fata Morgana* of the coast of Calabria, the gigantic spectre of the Brocken in the Hartz, the suspended images of concave mirrors, the visions of the phantasmagoria, the symmetrical reduplications of objects in the field of the kaleidoscope, and a multitude of other results of the simple combinations of the laws of optics.

The second class comprehends those in which the cause of deception is more internal, and consists in the peculiar condition of the nervous surface receiving the impressions. Ocular spectra of various kinds, impressions on the tongue and the eye from galvanism, and those which occasion singing in the ears, arising generally from an excited circulation, are among the many perceptions which rank under this head.

The third class of fallacies comprehends those which are essentially mental in their origin, and are the consequences of errors in our reasoning powers. Some of these have already been pointed out with regard to the perceptions of vision and of hearing, the formation of which is regulated

* In the Gulstonian Lectures, which I was appointed to read to the Royal College of Physicians, in May, 1832, I took occasion to enlarge on this subject. A summary of these lectures was given in the London Medical Gazette, vol. x. p. 273.

by the laws of the association of ideas. But even the sense of touch, which has been generally regarded as the least liable to fallacy, is not exempt from this source of error, as is proved by the well known experiment of feeling a single ball, of about the size of a pea, between two fingers which are crossed; for there is then a distinct perception of the presence of two balls instead of one.

But limited as our senses are in their range of perception, and liable to occasonal error, we cannot but perceive, that, both in ourselves, and also in every class of animals, they have been studiously adjusted, not only to the properties and the constitution of the material world, but, also, to the respective wants and necessities of each species, in the situations and circumstances where it has been placed by the gracious and beneficent Author of its being.

If the sensorial functions had been limited to mere sensation and perception, conjoined with the capacity of passive enjoyment and of suffering, the purposes of animal existence would have been but imperfectly accomplished; for, in order that the sentient being may secure the possession of those objects which are agreeable and salutary, and avoid or reject those which are painful or injurious, it is necessary that he should possess the power of spontaneous action. Hence, the faculty of *Voluntary Motion* is superadded to the other sensorial functions. The muscles which move the limbs, the trunk, the head, and organs of sense,—all those parts, in a word, which establish relations with the external world, are, through the intermedium of a separate set of nervous filaments, totally distinct from those which are subservient to sensation,* made to communicate directly with the sensorium, and are thereby placed under the direct control and guidance of the will. The mental act of volition is doubtless accompanied by some corresponding physical change in that part of the sensorium, whence the *motor nerves*, or

* On this subject I must refer the reader to the researches of Sir Charles Bell, and Magendie, who have completely established the distinction between these two classes of nerves.

those distributed to the muscles of voluntary motion, arise. Here, then, we pass from mental phenomena to such as are purely physical; and the impression, whatever may be its nature, originating in the sensorium, is propagated along the course of the nerve to those muscles, whose contraction is required for the production of the intended action. Of the function of voluntary motion, as far as concerns the moving powers and the mechanism of the instruments employed,* I have already treated at sufficient length in the first part of this work.

Every excitement of the sensorial powers is, sooner or later, followed by a proportional degree of exhaustion; and when this has reached a certain point, a suspension of the exercise of these faculties takes place, constituting the state of *sleep*, during which, by the continued renovating action of the vital functions, these powers are recruited, and rendered again adequate to the purposes for which they were bestowed. In the ordinary state of sleep, however, the exhaustion of the sensorium is seldom so complete as to preclude its being excited by internal causes of irritation, which would be scarcely sensible during our waking hours; and hence arise dreams, which are trains of ideas, suggested by internal irritations, and which the mind is bereft of the power to control, in consequence of the absence of all im-

* A voluntary action, occurring as the immediate consequence of the application of an external agent to an organ of the senses, though apparently a simple phenomenon, implies the occurrence of no less than twelve successive processes, as may be seen by the following enumeration. First, there is the modifying action of the organ of the sense, the refractions of the rays, for instance, in the case of the eye: secondly, the impression made on the extremity of the nerve: thirdly, the propagation of this impression along the nerve: fourthly, the impression or physical change in the sensorium. Next follow four kinds of mental processes, namely, sensation, perception, association, and volition. Then, again, there is another physical change taking place in the sensorium, immediately consequent on the mental act of volition: this is followed by the propagation of the impression downwards along the motor nerve; then an impression is made on the muscle; and, lastly, we obtain the contraction of the muscle, which is the object of the whole series of operations.

pressions from the external senses.* In many animals, a much more general suspension of the actions of life, extending even to the vital functions of respiration and circulation, takes place during the winter months, constituting what is termed *Hybernation*.

* The only indications of dreaming given by the lower animals occur in those possessed of the greatest intellectual powers, such as the *Dog*, among quadrupeds, and the *Parrot*, among birds.

CHAPTER VIII.

COMPARATIVE PHYSIOLOGY OF THE NERVOUS SYSTEM.

§ 1. *Nervous Systems of Invertebrated Animals.*

OUR knowledge of the exact uses and functions of the various parts which compose the nervous system, and especially of its central masses, is unfortunately too scanty to enable us to discern the correspondence, which undoubtedly exists, between the variations in the functions and the diversities in the organization. The rapid review which I propose to take of the different plans, according to which the nervous system is constructed in the several classes of animals, will show that these central masses are multiplied and developed in proportion as the faculties of the animal embrace a wider range of objects, and are carried to higher degrees of excellence.

In none of the lowest tribes of Zoophytes, such as *Sponges*, *Polypi*, and *Medusæ*, have any traces of organs, bearing the least analogy to a nervous system, been discovered; not even in the largest specimens of the last named tribe, some of which are nearly two feet in diameter. All these animals give but very obscure indications of sensibility; for the contractions they exhibit, when stimulated, appear to be rather the effect of a vital property of irritability than the result of any sensorial faculty. Analogy, however, would lead us to the belief that many of their actions are really prompted by sensations and volitions, though in a degree very inferior to those of animals higher in the scale of being; but whatever may be their extent, it is probable that the sensorial operations in these animals take place without the intervention of any common centre of action. It is at the same time remarkable that their movements are not effected by means of muscular fibres, as they are in all other animals, the granular flesh, of which their whole body is composed, appearing to have a generally diffused irritability, and perhaps also some degree of sensibility; so that each isolated granule may be supposed to be endowed with these combined properties, performing, independently of the other granules, the functions both of nerve and muscle. Such a mode of existence exhibits apparently the lowest and most rudimental condition of the animal functions. Yet the actions of the *Hydra*, of which I have given an account, are indicative of distinct volitions; as are also, in a still more decided manner, those of the *Infusoria*. In the way in which the latter avoid obstacles while swimming in the fluid, and turn aside when they encounter one another, and in the eagerness with which they pursue their prey, we can hardly fail to recognise the evidence of voluntary action.

To seek for an elucidation of these mysteries in the structure of animals whose minuteness precludes all accurate examination, would be a hopeless inquiry. Yet the indefatigable Ehrenberg has recently discovered, in some of the larger species of animalcules belonging to the order *Rotifera*, an organization, which he believes to be a nervous system. He observed, in the *Hydatina senta*, a series of six or seven gray bodies, enveloping the upper or dorsal part of the œsophagus, closely connected together, and perfectly distinguishable, by their peculiar tint, from the viscera and the surrounding parts. The uppermost of these bodies, which he considers as a ganglion, is much larger than the others, and gives off slender nerves, which, by joining another ganglion, situated under the integuments at the back of the neck, form a circle of nerves, analogous to that which surrounds the œsophagus in the mollusca: from this circle two slender nervous filaments are sent off to the head, and a larger branch to the abdominal surface of the body. The discovery of a regular structure of muscular bands of fibres, in these animalcules, is a farther evidence of the connexion which exists between nerves and muscles.

We again meet with traces of nervous filaments, accompanied also with muscular bands of fibres, in some of the more highly organized *Entozoa.* In the *Ascaris,* or long round worm, a slender and apparently single filament is seen passing forwards, along the lower side of the abdomen, till it reaches the œsophagus, where it splits into two branches, one passing on each side of that tube, but without exhibiting any ganglionic enlargement. This may be considered as the first step towards the particular form of the nervous system of the higher classes of articulated animals, where the principal nervous cord is obviously double throughout its whole length, or, if partially united at different points, it is always readily divisible into two, by careful manipulation. In addition to this characteristic feature, these cords present, in their course, a series of enlargements, appearing like knots; one pair of these generally corresponding to each of the segments of the body, and sending off, as from a centre, branches in various directions. It is probable that these knots, or ganglia, perform, in each segment of the worm, an office analogous to that of the brain and spinal marrow of vertebrated animals, serving as centres of nervous, and perhaps, also, of sensorial powers. Many facts, indeed, tend to show that each segment of the body of articulated animals, of an annular structure and cylindric form, such as the long worms and the myriapoda, has in many respects an independent sensitive existence, so that when the body is divided into two or more parts, each portion retains both the faculty of sensation, and the power of voluntary motion. As far as we can judge, however, the only external sense capable of being exercised by this simple form of nervous system, is that of touch; all the higher senses evidently requiring a much more developed and concentrated organization of nervous ganglia.

In this division of the animal kingdom, the primary nervous cords always pass along the middle of the lower surface of the body, this being the situation which, in the absence of a vertebral bony column, affords them the best protection. They may be considered as analogous to the spinal marrow, and as serving to unite the series of ganglia, through which they pass, into one connected system. On arriving at the œsophagus, they form round it a circle, or collar, studded with ganglia, of which the uppermost, or that nearest the head, is generally of greater size than the rest, and is termed the *œsophageal*, *cephalic*, or *cerebral* ganglion, being usually regarded as analogous to the brain of larger animals. Perhaps a more correct view of its functions would be conveyed by calling it the principal brain, and considering the other ganglia as subordinate brains. This large ganglion, which supplies an abundance of nervous filaments to every part of the head, seems to be the chief organ of the higher senses of vision, of hearing, of taste, and of smell, and to be instrumental in combining their impressions, so as to constitute an individual percipient animal, endowed with those active powers which are suited to its rank in the scale of being.

Such is the general form of the nervous system in all the *Annelida;* but in the higher orders of *Articulata* we find it exhibiting various degrees of concentration. The progress of this concentration is most distinctly traced in the *Crustacea.** One of the simplest forms of these organs occurs in a little animal of this class, which is often found in immense numbers, spread over tracts of sand on the sea shore, and which is called the *Talitrus locusta*, or Sand-

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hopper, (Fig. 438.) The central parts of its nervous system are seen in Fig. 439, which represents the abdominal side of this animal laid open, and magnified to twice the natural size. The two primary nervous

* See the account of the researches of Victor Audouin, and H. M. Edwards, on this subject, given in the Ann. des Sc. Nat. xix. 181.

cords, which run in a longitudinal direction, are here perfectly distinct from one another, and even separated by a small interval: they present a series of ganglia, which are nearly of equal size, and equidistant from one another, one pair corresponding to each segment of the body,* and united by transverse threads; and other filaments, diverging laterally, proceed from each ganglion. During the progress of growth, the longitudinal cords approach somewhat nearer to each other, but still remain perfectly distinct. The first

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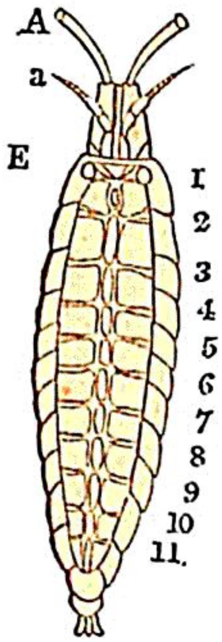

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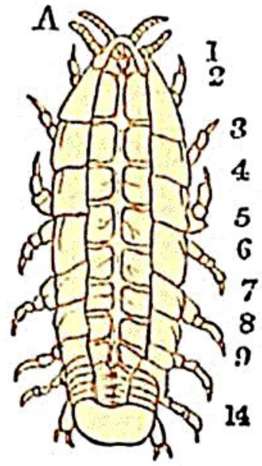

pair of ganglia, or the *cephalic*, have been considered, though improperly, as the brain of the animal.

The next step in the gradation occurs in the *Phyllosoma* (Leach,) where the ganglia composing each pair in the abdomen and in the head, are united into single masses, while those in the thoracic region are still double. In the *Cymothoa*, (Fab.,) which belongs to the family of *Oniscus*, there is the appearance of a single chain of ganglia, those on the one side having coalesced with those on the other; each pair composing a single ganglion, situated in the middle line; while the longitudinal cords which connect them still re-

* These segments are numbered in this and the following figure in their proper order, beginning with that near the head. A is the external antenna; a, the internal antenna; and E the eye.

main double, as is shown in Fig. 440, which represents the interior of this crustaceous animal, nearly of the natural size. But in the higher orders of crustacea, as in the *Lobster*, these longitudinal cords are themselves united in the abdominal region, though still distinct in the thorax.

In following the ascending series of crustaceous animals, we observe also an approximation of the remoter ganglia towards those near the centre of the body: this tendency already shows itself in the shortening of the hinder part of the nervous system of the *Cymothoa*, as compared with the *Talitrus;* and the concentration proceeds farther in other tribes. In the *Palemon*, for example, most of the thoracic ganglia, and in the *Palinurus* (Fab.,) all of them, have coalesced into one large oval mass, perforated in the middle, and occupying the centre of the thorax; and, lastly, in the *Maia squinado*, or Spider Crab (Fig. 441,* this mass

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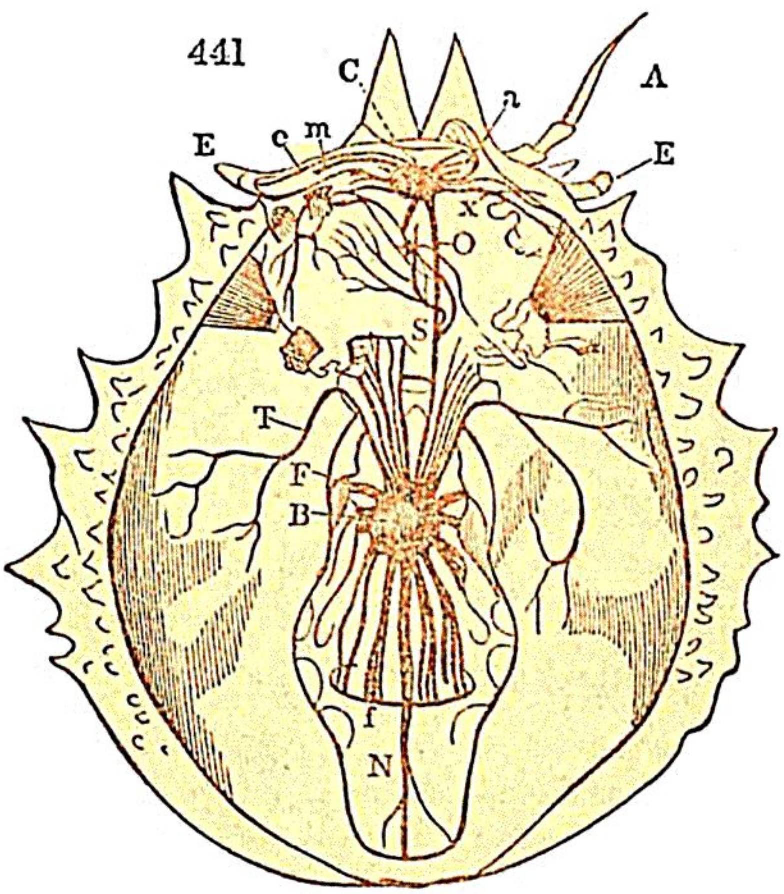


* In this figure are seen the great thoracic ganglion (B,) from which proceed the superior thoracic nerves (T,) those to the fore feet (F,) to the hinder

acquires still greater compactness, assumes a more globular form, and has no central perforation.

These different forms of structure are also exemplified in the progress of the development of the higher Crustacea: thus, in the *Lobster*, the early condition of the nervous system is that of two separate parallel cords, each having a distinct chain of ganglia, as is the case in the Talitrus: then the cords are observed gradually to approximate, and the ganglia on each side to coalesce, as represented in the *Cymothoa;* and at the period when the limbs begin to be developed, the thoracic ganglia approach one another, unite in clusters, and acquire a rapid enlargement, preparatory to the growth of the extremities from that division of the body; the abdominal ganglia remaining of the same size as before. The cephalic ganglion, which was originally double, and has coalesced into one, is also greatly developed, in correspondence with the growth of the organs of sense. The next remarkable change is that taking place in the hinder portions of the nervous cords, which are shortened, at the same time that their ganglia are collected into larger masses, preparatory to the growth of the tail and hinder feet; so that throughout the whole extent of the system the number of ganglia diminishes in the progress of development, while their size is augmented.

All *Insects* have the nervous system constructed on the same general model as in the last mentioned classes; and it assumes, as in the Crustacea, various degrees of concentration in the different stages of development. As an example we may take the nervous system of the *Sphinx ligustri*, of which representations are given in the larva, pupa, and ima-

feet (f,) and the abdominal nervous trunk (N;) the cephalic ganglion (c,) communicating by means of two nervous cords (o,) which surround the œsophagus and entrance into the stomach (s,) with the thoracic ganglion (B;) and sending off the optic nerve (e) to the eyes (E,) and the motor nerves (m,) to the muscles of those organs; and also the nerves (a) to the internal antennæ, and the nerves (x) to the external antennæ (A.)

go states, wholly detached from the body, and of their natural size, in Figures 442, 443, and 444.*

This system in the larva (Fig. 442) has the same simple form as in the Annelida, or in the Talitrus, for it consists of

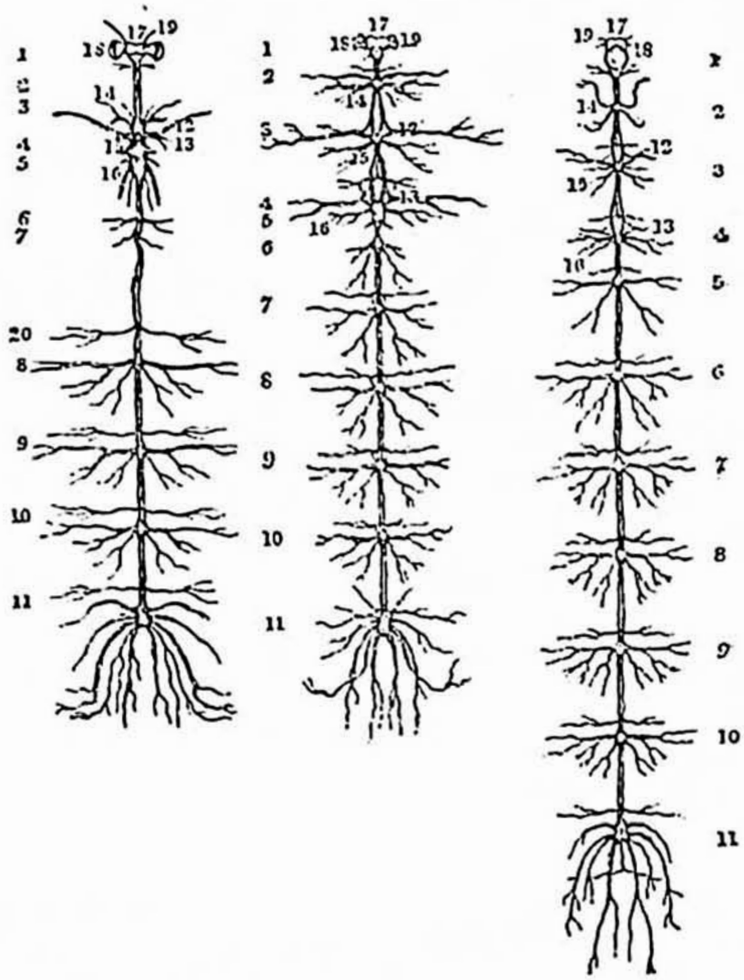
* These figures were drawn by Mr. Newport, from original preparations made by himself. The same numbers in each refer to the same parts; so that by comparing the figures with one another, a judgment may be formed of the changes of size and situation which occur in the progress of the principal transformations of the insect. Numbers 1 to 11 indicate the series of ganglia which are situated along the under side of the body, and beneath the alimentary canal. Of these the first five are the thoracic, and the last six the abdominal ganglia; while the cephalic, or cerebral ganglion (17) is situated above the œsophagus and dorsal vessel, and communicates by two nervous chords with the first of the series, or sub-œsophageal ganglion (1,) which is, in every stage of the insect, contained within the head, and distributes nerves to the parts about the mouth. The next ganglion (2) becomes obliterated at a late period of the change from the pupa to the imago state: the third (3) remains, but the two next (4, 5) coalesce to form, in the imago, the large thoracic ganglion; while the two which follow (6 and 7,) become wholly obliterated before the insect attains the imago state, the intervening cords becoming shorter, and being, with the nerves they send out, carried forwards. The last four (8, 9, 10, 11) of the abdominal ganglia remain, with but little alteration, in all the stages of metamorphosis: in the larva, they supply nerves to the false feet. The nerves (12, 13) which supply the wings of the imago, are very small in the larva; and they arise by two roots, one derived from the cord, and one from the ganglion. The nerves sent to the three pairs of anterior, or true legs, are marked 14, 15, 16.

The nervous system of the larva is exhibited in Fig. 442, that of the pupa in Fig. 443, and that of the imago in Fig. 444. It will be seen that in the pupa the abdominal ganglia are but little changed; but those situated more forward (6, 7) are brought closer together by the shortening of the intervening cord, preparatory to their final obliteration in the imago; a change which those in front of them (4, 5) have already undergone. The progressive development of the optic (18) and antennal (19) nerves may also be traced. Mr. Newport has also traced a set of nerves (20) which arise from distinct roots, and which he found to be constantly distributed to the organs of respiration.

A detailed account of the anatomy of the nervous system of the *Sphinx ligustri*, and of the changes it undergoes up to a certain period, is given by Mr. Newport in a paper in the Phil. Trans. for 1832, p. 383. He has since completed the inquiry to the last transformation of this and other insects, and has lately presented to the Royal Society an account of his researches.

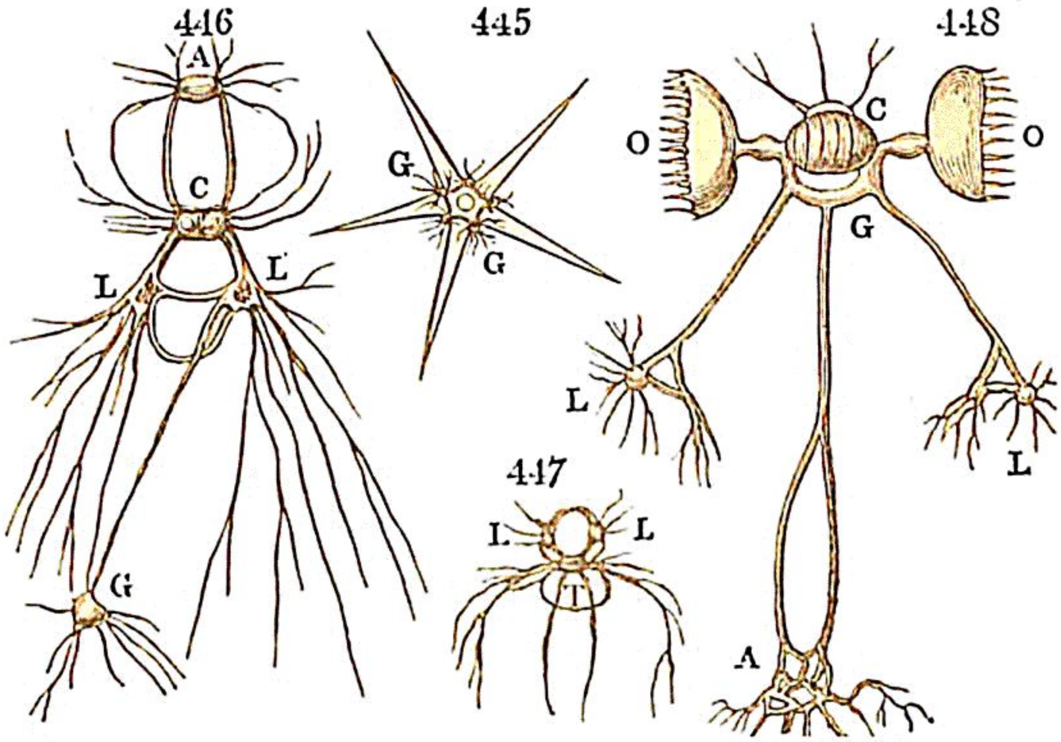
a longitudinal series of ganglia, usually twelve or thirteen in number, connected in their whole length by a double filament. By degrees the different parts of which it consists approach each other, the thoracic ganglia, in particular, coalescing into larger masses, and becoming less numerous, some being apparently obliterated; the whole cord becomes in con-

444 443 442



sequence shorter, and the abdominal ganglia are carried forwards. The optic nerves are greatly enlarged during the latter stages of transformation, and each of them is often of greater magnitude than the brain itself. A set of nerves has also been discovered, the course of which is peculiar, and appears to correspond with the sympathetic or ganglionic system of nerves in vertebrated animals, while another nerve resembles in its mode of distribution, the *pneumo-gastric* nerve, or *par vagum*. Very recently Mr. Newport has distinctly traced a separate nervous tract, which he conceives gives origin to the motor nerves, while the subjacent column sends out the nerves of sensation.

In the next great division of the animal kingdom, which includes all molluscous animals, the nervous ganglia have a circular, instead of a longitudinal arrangement. The first example of this type occurs in the *Asterias*, where the nervous system (Fig. 445) is composed of small ganglia, equal



in number to the rays of the animal, and disposed in a circle round the central aperture or mouth, but occupying situations intermediate between each of the rays. A nerve is sent off from both sides of each ganglion, and passes along the side of the rays, each ray receiving a pair of these nerves. In the *Holothuria* there is a similar chain of ganglia, encircling the œsophagus; and the same mode of arrangement prevails in all the bivalve *Mollusca*, except that, besides the œsophageal ganglia, others are met with in different parts of the body, distributing branches to the viscera, and connected with one another and with the œsophageal ganglia, by filaments, so as to form with them one continuous nervous system. In the Gasteropoda, which are furnished with a distinct head and organs of the higher senses, (such as the *Aplysia*, of which the nervous system is exhibited in Fig. 446,) there is generally a special cephalic ganglion (C,) which may be supposed to serve the office of brain.* In others, again, as in the *Patella*, (Fig. 447,) the cephalic ganglion is scarcely discernible, and its place is supplied by two lateral ganglia (L. L;) and there is besides a transverse ganglion (T,) below the œsophagus. The cephalic ganglion, on the other hand, attains a considerable size in the Cephalopoda (C, Fig. 448,) where it has extensive connexions with all the parts of the head: the optic ganglia (O, O,) in particular, are of very great size, each of them, singly, being larger than the brain itself.†

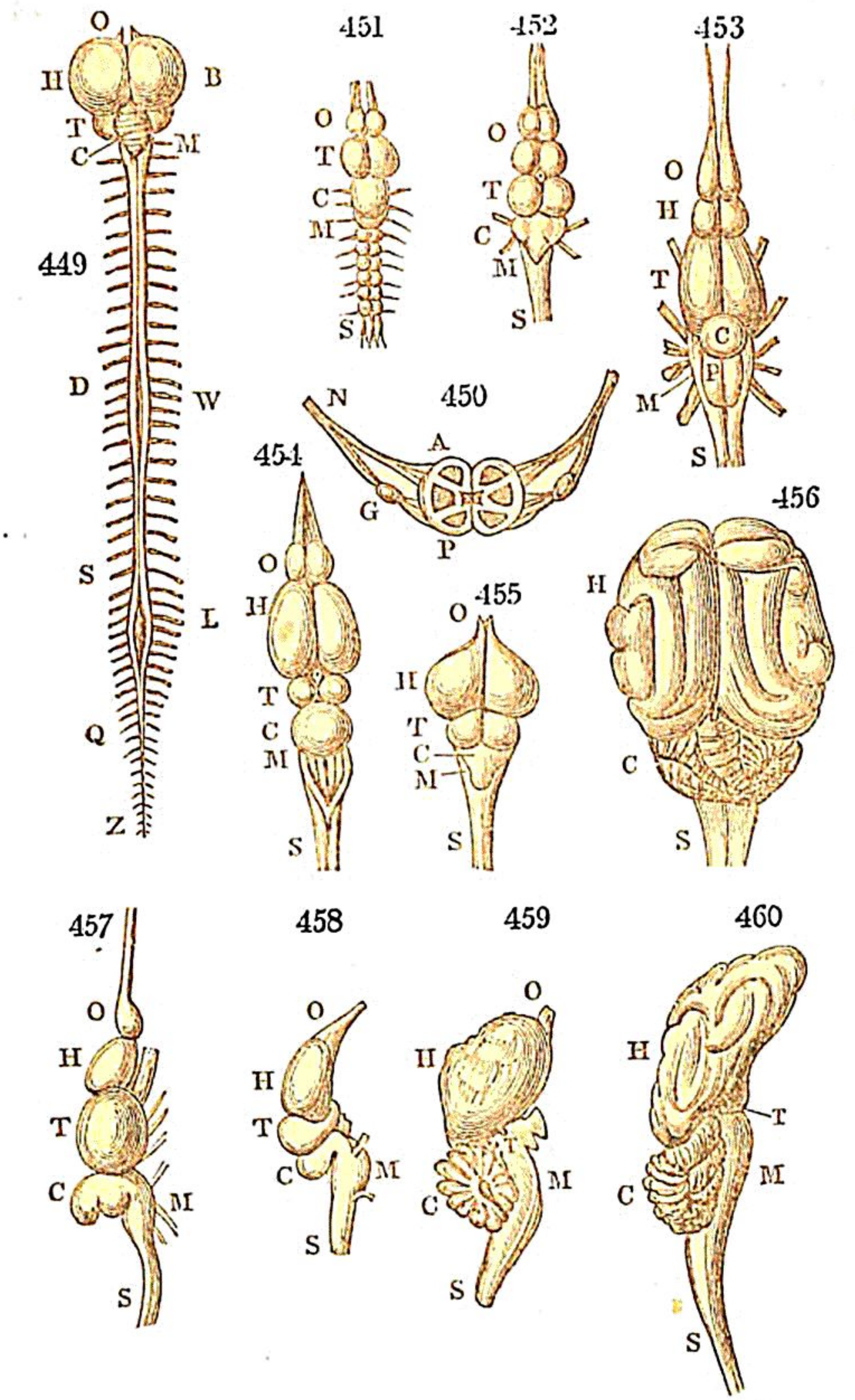
§ 2. *Nervous System of Vertebrated Animals.*

THE characteristic type of the nervous system of vertebrated animals is that of an elongated cylinder of nervous matter, (M, Z, Fig. 449,) extending down the back, and lodged in the canal formed by the grooves and arches of the vertebræ. It has received the name of spinal marrow, or more properly, spinal cord; and, (as is seen in the transverse section, Fig. 450,) is composed of six parallel columns, two posterior, two middle, and two anterior, closely joined together, but leaving frequently a central canal, which is filled with fluid. On each side of the spinal cord, and between all the adjacent vertebræ, there proceed two sets of nervous filaments, those which are continuous with the posterior columns (P,) being appropriated to the function of sensation; and those arising from the anterior columns (A,) being sub-

* This figure also shows a ganglion (A,) which is placed higher, and communicates by lateral filaments with the cephalic ganglion (C;) two lateral ganglia (L, L,) of great size; and a large abdominal ganglion (G.)

† Some peculiarities in the structure of the cephalic ganglion of the Sepa have been supposed to indicate an approach to the vertebrated structure; for this ganglion, together with the labyrinth of the ear, is enclosed in a cartilaginous ring, perforated at the centre to allow of the passage of the œsophagus, and imagined to be analogous to a cranium.

servient to voluntary motion. The former, soon after their exit from the spine, pass through a small ganglion (G,) and



then unite with the nerves from the anterior column, composing, by the intermixture of their fibres, a single nervous trunk (N,) which is afterwards divided and subdivided in the course of its farther distribution, both to the muscular and the sentient organs of the body. Each of these spinal nerves also sends branches to the ganglia of the sympathetic nerve, which, as was formerly described, passes down on each side, parallel and near to the spine.

Enlargements of the spinal marrow are observed in those parts, (w and L, Fig. 449,) which supply the nerves of the extremities, the increase of diameter being proportional to the size of the limbs requiring these nerves. In Serpents, which are wholly destitute of limbs, the spinal marrow is not enlarged in any part, but is a *cylindrical column* of uniform diameter. In Fishes, these enlargements appear to have a relation to the size of the organs of motion or sensation, and correspond to them in their situation. Thus in the *Trigla lyra*, (the Red or Piper Gurnard,) and the *Trigla Gurnardus* (the Gray Gurnard,) there are, at the commencement of the spinal marrow, numerous enlargements, presenting a double row of tubercles, (as seen in the space between M and S, Fig. 451.) The nerves from these tubercles supply the detached rays, or feelers, anterior to the pectoral fin. Fishes which possess electrical organs have a considerable dilatation of the spinal marrow, answering to the large nerves which are distributed to those organs. Birds which fly but imperfectly as the *Gallinaceous* tribe and the *Scansores*, have the posterior enlargement much greater than the anterior; a disproportion which is particularly remarkable in the *Ostrich*. On the contrary, the anterior enlargement is much more considerable than the posterior in birds which have great power of flight. In the Dove, of which the brain and whole extent of the spinal marrow are shown in Fig. 449, the enlargements (w and L) corresponding to the wings and legs respectively, and nearly of equal size. In Quadrupeds, we likewise find the relative size of these enlargements corresponding to that of fore and hind extremities. When the latter are absent, as in the *Cetacea*, the posterior dilatation does not exist.

The brain (B) may be regarded as an expansion of the anterior or upper end of the spinal marrow; and its magnitude, as well as the relative size of its several parts, vary much in the different classes and families of vertebrated animals. This will appear from the inspection of the figures I have given of this organ in various species, selected as specimens from each class, viewed from above; and in all of which I have indicated corresponding parts by the same letters of reference.

The portion (M) of the brain, which appears as the immediate continuation of the spinal marrow (S,) is termed the *medulla oblongata*. The single tubercle (C,) arising from the expansion of the posterior columns of the spinal marrow, is termed the cerebellum, or little brain. Next follow the pair (T) which are termed the optic tubercles, or lobes,* and appear to be productions from the middle columns of the spinal marrow. These are succeeded by another pair of tubercles (H,) which are called the *cerebral hemispheres*, and the origin of which may be traced to the anterior columns of the spinal marrow. There is also generally found, in front of the hemispheres, another pair of tubercles (O,) which being connected with the nerves of smelling, have been called the *olfactory lobes* or *tubercles*.† These are the principal parts of the cerebral mass to be here noticed, for I purposely omit the mention of the minuter divisions, which, though they have been objects of much attention to anatomists, unfortunately furnish no assistance in understanding the physiology of this complicated and wonderful organ.

On comparing the relative proportions of the brain and of the spinal marrow in the four classes of vertebrated animals, a progressive increase in the size of the former will be observed as we ascend from Fishes to Reptiles, Birds, and Mammalia. This increase in the magnitude of the brain arises chiefly from the enlargement of the cerebral hemispheres (H,) which, in the inferior orders of fishes, as in the

* In the Mammalia, and in Man, they have been often designated by the very inappropriate name of *Corpora quadrigemina*.

† Several cavities, termed *Ventricles*, are occasionally found in the interior of the principal tubercles of the brain; but their use is unknown.

Trigla lyra, or Piper Gurnard, (Fig. 451,) and in the *Muræna conger* or Conger Eel, (Fig. 452,) are scarcely discernible. They are very small in the *Perca fluviatilis*, or common Perch (Fig. 453;) but more developed in Reptiles, as in the *Testudo mydas*, or Green Turtle, (Fig. 454,) and in the *Crocodile*, (Fig. 455;) and still more so in Birds, as is seen in the brain of the *Dove*, (Fig. 449;) but, most of all, in Mammalia, as is exemplified in the brain of the *Lion*, (Fig. 456.) On the other hand, the optic tubercles (T) are largest, compared with the rest of the brain, in Fishes; and their relative size diminishes as we ascend to Mammalia; and the same observation applies also to the olfactory lobes, (O.)

The relative positions of the parts of the brain are much influenced by their proportional development. This will be rendered manifest by the lateral views of the brains of the Perch, the Turtle, the Dove, and the Lion, presented in Figures 457, 458, 459, and 460, respectively, where the same letters are employed to designate the same parts as in the preceding figures. In Fishes, all the tubercles which compose this organ, are disposed nearly in a straight line, continuous with the spinal marrow, of which, as they scarcely exceed it in diameter, they appear to be mere enlargements. As the skull expands more considerably than the brain, this organ does not fill its cavity, but leaves a large space filled with fluid. Some degree of shortening, however, may be perceived in the brain of the *Perch* (Fig. 457;) for the medulla oblongata (M) is doubled underneath the cerebellum (C,) pushing it upwards, and rendering it more prominent than the other tubercles. This folding inwards, and shortening of the whole mass, proceeds to a greater extent as we trace the structure upwards, as may be seen in the brain of the *Green Turtle* (Fig. 458.) In that of Birds, of which Fig. 459 presents a vertical section, the optic tubercles have descended from their former place, and assumed a lateral position, near the lower surface of the brain, lying on each side of the medulla oblongata, at the part indicated by the letter

T. In Mammalia, as in the *Lion* (Fig. 460,) they are lodged quite in the interior of the organ, and concealed by the expanded hemispheres (H;) their position only being marked by the same letter (T.) These changes are consequences of the increasing development of the brain, compared with that of the cavity in which it is contained, requiring every part to be more closely packed; thus, the layers of the hemispheres in Mammalia are obliged, from their great extent, to be plaited and folded on one another, presenting at the surface curious windings, or *convolutions*, as they are called (seen in Fig. 456,) which do not take place in the hemispheres of the inferior classes. The foldings of the substance of the cerebellum produce, likewise, even in birds, transverse furrows on the surface; and from the interposition of a substance of a gray colour between the laminæ of the white medullary matter, a section of the cerebellum presents the curious appearance (seen in Fig. 459,) denominated, from its fancied resemblance to a tree, the *Arbor Vitæ*.

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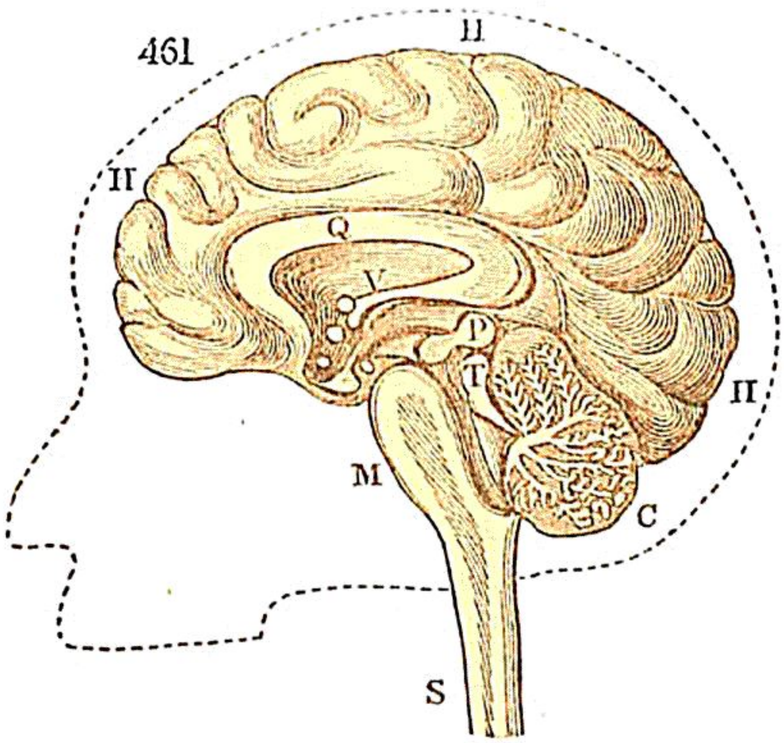

Thus far we have followed an obvious gradation in the development and concentration of the different parts of the brain; but on arriving at Man, the continuity of the series is suddenly disturbed by the great expansion of the hemispheres, (Fig. 461,) which, compared with those of quadrupeds, bear no sort of proportion to the rest of the nervous system. Both Aristotle and Pliny have asserted that the absolute, as well as the comparative size of the human brain is greater than in any other known animal; exceptions, however, occur in the case of the *Elephant*, and also in that of the *Whale*, whose brains are certainly of greater absolute bulk than that of man. But all the large animals, with which we are familiarly acquainted, have brains considerably smaller; as will readily appear from an examination of their skulls, which are narrow and compressed at the part occupied by the brain; the greater part of the head being taken up by the development of the face and jaws. In Man, on the other hand, the bones of the skull rise perpendicularly from the forehead, and are extended on each side, so as to form a capacious globular cavity for the reception and defence of this most important organ. It is chiefly from the expansion of the hemispheres, and the development of its convolutions, that the human brain derives this great augmentation of size.*

* This will be apparent from the vertical section of the human brain, Fig. 461; where, as before, s is the spinal marrow; M, the medulla oblongata; C, the cerebellum, with the *arbor vitæ;* T, the optic tubercles, or corpora quadrigemina, dwindled to a very small size, compared with their bulk in fishes: P, the pineal gland, supposed by Des Cartes to be the seat of the soul; V, one of the lateral ventricles; Q, the corpus callosum; and H, H, H, the hemispheres.

Several expedients have been proposed for estimating the relative size of the brain in different tribes of animals, with a view of deducing conclusions as to the constancy of the relation which is presumed to exist between its greater magnitude and the possession of higher intellectual faculties. The most celebrated is that devised by Camper, and which he termed the *facial angle*, composed of two lines, one drawn in the direction of the basis of the skull, from the ear to the roots of the upper incisor teeth, and the other from the latter point, touching the most projecting part of the forehead. Camper conceived that the magnitude of this angle would correctly indicate the size of the brain, as compared with the organs of the principal senses which

§ 3. *Functions of the Brain.*

Physiologists have in all ages sought for an elucidation of the functions of the brain by the accurate examination of its structure, which evidently consists of a congeries of medullary fibres, arranged in the most intricate manner. Great pains have been bestowed in unravelling the tissue of these fibres, in the hope of discovering some clew to the perplexing labyrinth of its organization; but nearly all that has been learned from the laborious inquiry is, that the fibres of the brain are continuous with those which compose the columns of the spinal marrow; that they pass, in their course, through masses of nervous matter, which appear to be analogous to ganglia; and that their remote extremities extend to the surface of the convolutions of the brain and cerebellum, which are composed of a softer and more transparent gray matter, termed the *cortical* or *cineritious substance* of the brain.

It is a remarkable fact, that in vertebrated animals all the organs which are subservient to the sensorial functions are double, those on one side being exactly similar to those on the other. We see this in the eyes, the ears, the limbs, and all the other instruments of voluntary motion; and in like manner the parts of the nervous system which are connected with these functions are all double, and arranged symmetrically on the two sides of the body. The same law of symmetry extends to the brain; every part of that organ which is found on one side is repeated on the other; so that, strictly speaking, we have two brains, as well as two optic nerves and two eyes. But in order that the two sets of fibres may co-operate, and constitute a single organ of sensation, corresponding with our consciousness of individuality, it was necessary that a free communication should be

compose the face; but the fallacy of this criterion of animal sagacity has been shown in a great many cases.

established between the parts on both sides. For this purpose there is provided a set of medullary fibres, passing directly across from one side of the brain to the other; these constitute what are called the *Commissures* of the brain.*

The question, however, still recurs:—What relation does all this artificial intertexture and accumulation of fibres bear to the mental operations of which we are conscious, such as memory, abstraction, thought, judgment, imagination, volition? Are there localities set apart for our different ideas in the storehouse of the cerebral hemispheres, and are they associated by the material channels of communicating fibres? Are the mental phenomena the effects, as was formerly supposed, of a subtle fluid, or *animal spirits*, circulating with great velocity along invisible canals in the nervous substance? or shall we, with Hartley, suppose them to be the results of *vibrations* and *vibratiuncles*, agitating in succession the finer threads of which this mystic web has been constructed? A little reflection will suffice to convince us that these, and all other mechanical hypotheses, which the most fanciful imagination can devise, make not the smallest approach to a solution of the difficulty; for they, in fact, do not touch the real subject to be explained, namely, how the affections of a material substance can influence and be influenced by an immaterial agent. All that we have been able to accomplish has been to trace the impressions from the organ of sense along the communicating nerve to the sensorium: beyond this the clew is lost, and we can follow the process no farther.

* The principal commissure of the human brain, called the *corpus callosum*, is seen at *a*, Fig. 461. Dr. Macartney, in a paper which he read at the late meeting at Cambridge of the British Association for the Advancement of Science, described the structure of the human brain, as discovered by his peculiar mode of dissection, to be much more complicated than is generally supposed. He observed that its fibres are interlaced in the most intricate manner, resembling the plexuses met with among the nerves, and establishing the most extensive and general communications between every part of the cerebral mass.

The exact locality of the sensorium has been eagerly sought for by physiologists in every age. It would appear, from the results of the most recent inquiries, that it certainly does not extend to the whole mass of the brain, but has its seat more especially in the lower part, or basis of that organ. It differs, however, in its locality, in different classes of animals. In man, and the mammalia which approach the nearest to him in their structure, it occupies some part of the region of the medulla oblongata, probably the spot where most of the nerves of sense are observed to terminate. In the lower animals it is not confined to this region, but extends to the upper part of the spinal marrow. As we descend to the inferior orders of the animal kingdom, we find it more and more extensively diffused over the spinal marrow; and in the Invertebrata the several ganglia appear to be endowed with this sensorial property; but, becoming less and less concentrated in single masses, the character of individuality ceases to attach to the sensorial phenomena; until, in Zoophytes, we lose all traces of ganglia and of nervous filaments, and every part appears to possess an inherent power of exciting sensation, as well as performing muscular contractions.

Beyond this point we can derive no farther aid from Anatomy, since the intellectual operations of which we are conscious bear no conceivable analogy to any of the configurations or actions of a material substance. Although the brain is constructed with evident design, and composed of a number of curiously wrought parts, we are utterly unable to penetrate the intention with which they are formed, or to perceive the slightest correspondence which their configuration can have with the functions they respectively perform. The map of regions which modern Phrenologists have traced on the surface of the head, and which they suppose to have a relation to different faculties and propensities, does not agree either with the natural divisions of the brain or with the metaphysical classification of mental phenomena.* Experiments and pathological observations, however, seem to show that the hemispheres of the brain are the chief instruments by which the intellectual operations are carried on; that the central parts, such as the optic lobes and the medulla oblongata, are those principally concerned in sensation; and that the cerebellum is the chief sensorial agent in voluntary motion.

§ 4. *Comparative Physiology of Perception.*

Of the perceptions of the lower animals, and of the laws which they obey, our knowledge must, of necessity, be extremely imperfect, since it must be derived from a comparison with the results of our own sensitive powers, which may differ very essentially from those of the subjects of our observation. The same kind of organ which, in ourselves, conveys certain definite feelings, may, when modified in other animals, be the source of very different kinds of sensations and perceptions, of which our minds have not the power to form any adequate conception. Many of the qualities of surrounding bodies, which escape our more obtuse senses, may be distinctly perceived, in all their gradations, by particular tribes of animals, furnished with more delicate organs. Many quadrupeds and birds possess powers of vision incomparably more extensive than our own; in acuteness of hearing, we are excelled by a great number of animals, and in delicacy of taste and smell, there are few quadrupeds that do not far surpass us. The organ of smell, in particular, is often spread over a vast extent of surface, in a cavity occupying the greatest part of the head; so that the perceptions of this sense must be infinitely diversified.

* For a summary of the doctrines of Drs. Gall and Spurzheim, I beg leave to refer the reader to an account which I drew up, many years ago, for the Encyclopædia Britannica, and which composed the article "Cranioscopy" in the last supplement to that work, edited by Mr. Napier.

Bats have been supposed to possess a peculiar, or sixth sense, enabling them to perceive the situations of external objects without the aid either of vision or of touch. The principal facts upon which this opinion has been founded were discovered by Spallanzani, who observed that these animals would fly about rapidly in the darkest chambers, although various obstacles were purposely placed in their way, without striking against or even touching them. They continued their flight with the same precision as before, threading their way through the most intricate passages, when their eyes were completely covered, or even destroyed. Mr. Jurine, who made many experiments on these animals, concludes that neither the sense of touch, of hearing or of smell, was the medium through which bats obtain perceptions of the presence and situation of surrounding bodies; but he ascribes this extraordinary faculty to the great sensibility of the skin of the upper jaw, mouth, and external ear, which are furnished with very large nerves.*

The wonderful acuteness and power of discrimination which many animals exercise in the discovery and selection of their food, has often suggested the existence of new senses, different from those which we possess, and conveying peculiar and unknown powers of perception. An organ, which appears to perform some sensitive function of this kind, has been discovered in a great number of quadrupeds by Jacobson.† In the human skeleton there exists a small perforation in the roof of the mouth, just behind the sockets of the incisor teeth, forming a communication with the under and fore part of the nostrils. This canal is perceptible only in the dried bones; for, in the living body, it is completely closed by the membrane lining the mouth, which sends a prolongation into it: but in quadrupeds, this passage is pervious even during life, and is sometimes of considerable width. Jacobson found, on examining this structure with

* Sir Anthony Carlisle attributes this power to the extreme delicacy of hearing in this animal.

† See Annales du Musée; xviii. 412.

attention, that the canal led to two glandular organs of an oblong shape, and enclosed in cartilaginous tubes: each gland has in its centre a cavity which communicates above with the general cavity of the nostrils. These organs lie concealed in a hollow groove within the bone, where they are carefully protected from injury: and they receive a great number of nerves and blood vessels, resembling in this respect the organs of the senses. Their structure is the same in all quadrupeds in which they have been examined; but they are largest in the family of the *Rodentia*, and next in that of the *Ruminantia;* in the Horse, they are still very large, but the duct is not pervious; while, in carnivorous quadrupeds, they are on a smaller scale. In *Monkeys*, they may still be traced, although extremely small, appearing to form a link in the chain of gradation connecting this tribe with the human race, in whom every vestige of these organs has disappeared, excepting the aperture in the bones already noticed. Any use that can be attributed to these singularly constructed organs must evidently be quite conjectural. The ample supply of nerves which they receive would indicate their performing some sensitive function; and their situation would point them out as fitting them for the appreciation of objects presented to the mouth to be used as food; hence it is probable that the perceptions they convey have a close affinity with those of smell and taste.

The larger cartilaginous fishes, as *Sharks* and *Rays*, have been supposed by Treviranus to be endowed with a peculiar sense, from their having an organ of a tubular structure on the top of the head, and immediately under the skin; Roux considers it as conveying sensations intermediate between those of touch and hearing; while De Blainville and Jacobson regard it merely as the organ of a finer touch.

The perceptive powers of *Insects* must embrace a very different, and, in many respects, more extended sphere than our own. These animals manifest by their actions that they perceive and anticipate atmospheric changes, of which our senses give us no information. It is evident, indeed, that the impressions made by external objects on their sentient organs must be of a nature widely different from those which the same objects communicate to ourselves. While with regard to distance and magnitude our perceptions take a wider range, and appear infinitely extended when compared with those of insects, yet they may, in other respects, be greatly inferior. The delicate discrimination of the more subtle affections of matter is, perhaps, compatible only with a minute scale of organization. Thus, the varying degrees of moisture or dryness of the atmosphere, the continual changes in its pressure, the fluctuations in its electrical state, and various other physical conditions, may be objects of distinct perception to these minute animals. Organs may exist in them, appropriated to receive impressions, of which we can have no idea; and opening avenues to various kinds of knowledge, to which we must ever remain utter strangers. Art, it is true, has supplied us with instruments for discovering and measuring many of the properties of matter, which our unassisted senses are inadequate to observe. But neither our thermometers, nor our electroscopes, our hygrometers, nor our galvanometers, however skilfully devised or elaborately constructed, can vie in delicacy and perfection with that refined apparatus of the senses which nature has bestowed on even the minutest insect. There is reason to believe, as Dr. Wollaston has shown, that the hearing of insects comprehends a range of perceptions very different from that of the same sense in the larger animals; and that a class of vibrations too rapid to excite our auditory nerves, is perfectly audible to them. Sir John Herschel has also very clearly proved that, if we admit the truth of the undulatory theory of light, it is easy to conceive how the limits of visible colour may be established; for if there be no nervous fibres in unison with vibrations, more or less frequent than certain limits, such vibrations, though they reach the retina, will produce no sensation. Thus, it is perfectly possible that insects, and other animals, may be incapable of being affected by any of the colours which we perceive; while they may be susceptible of receiving distinct luminous impressions from a class of vibrations which, applied to our visual organs, excite no sensation.* The functions of the antennæ, which, though of various forms, are organs universally met with in this class of animals, must be of great importance, though obscurely known; for insects when deprived of them appear to be quite lost and bewildered.

The *Torpedo*, the *Gymnotus*, and several other fishes, are furnished with an electrical apparatus, resembling the Voltaic battery, which they have the power of charging and discharging at pleasure. An immense profusion of nerves is distributed upon this organ; and we can hardly doubt that they communicate perceptions, with regard to electricity, very different from any that we can feel. In general, indeed, it may be remarked, that the more an organ of sense differs in its structure from those which we ourselves possess, the more uncertain must be our knowledge of its functions. We may, without any great stretch of fancy, conceive ourselves placed in the situation of the beasts of the forest, and comprehend what are the feelings and motives which animate the quadruped and the bird. But how can we transport ourselves, even in imagination, into the dark recesses of the ocean, which we know are tenanted by multitudinous tribes of fishes, zoophytes, and mollusca? How can we figure to ourselves the sensitive existence of the worm or the insect, organized in so different a manner from ourselves, and occupying so remote a region in the expanse of creation? How can we venture to speculate on the perceptions of the animalcule, whose world is a drop of fluid, and whose fleeting existence, chequered, perhaps, by various transformations, is destined to run its course in a few hours?

Confining our inquiries, then, to the more intelligible intellectual phenomena displayed by the higher animals, we readily trace a gradation which corresponds with the development of the central nervous organ, or brain. That the

* Encyclopædia Metropolitana, Article "LIGHT."

comparison may be fairly made, however, it is necessary to distinguish those actions which are the result of the exercise of the intellectual faculties, from those which are called instinctive, and are referrible to other sources. The actions of animals appear on various occasions, to be guided by a degree of sagacity not derivable from experience, and apparently implying a foreknowledge of events, which neither experience nor reflection could have led them to anticipate. We cannot sufficiently admire the provident care displayed by nature in the preservation both of the individual and of the species, which she has intrusted, not to the slow and uncertain calculations of prudence, but to innate faculties, prompting, by an unerring impulse, to the performance of the actions required for those ends. We see animals providing against the approach of winter, the effects of which they have never experienced, and employing various means of defence against enemies they have never seen. The parent consults the welfare of the offspring she is destined never to behold; and the young discovers and pursues without a guide that species of food which is best adapted to its nature. All these unexplained, and, perhaps, inexplicable facts, we must content ourselves with classing under the head of *instinct*, a name which is, in fact, but the expression of our ignorance of the nature of that agency, of which we cannot but admire the ultimate effects, while we search in vain for the efficient cause.

In all the inferior orders of the animal creation, where instincts are multiplied, while the indications of intellect are feeble, the organ which performs the office of the brain is comparatively small. The sensitive existence of these animals appears to be circumscribed within the perceptions of the moment, and their voluntary actions have reference chiefly to objects which are present to the sense. In proportion as the intellectual faculties of animals are multiplied, and embrace a wider sphere, additional magnitude and complication of structure are given to the nervous substance which is the organ of those faculties. The greater the power of combining ideas, and of retaining them in the memory, the greater do we find the development of the cerebral hemispheres. These parts of the brain are comparatively small, as we have seen, in fishes, reptiles, and the greater number of birds; but in the mammalia they are expanded in a degree nearly proportional to the extent of memory, sagacity and docility. In man, in whom all the faculties of sense and intellect are so harmoniously combined, the brain is not only the largest in its size, but beyond all comparison the most complicated in its structure.*

A large brain has been bestowed on man, evidently with the design that he should exercise superior powers of intellect; the great distinguishing features of which are the capacity for retaining an immense variety of impressions, and the strength, the extent, and vast range of the associating principle, which combines the minto groups, and forms them into abstract ideas. Yet the lower animals also possess their share of memory, and of reason; they are capable of acquiring knowledge from experience; and, on some rare occasions, of devising expedients for accomplishing particular ends. But still this knowledge and these efforts of intellect are confined within very narrow limits; for nature has assigned boundaries to the advancement of the lower animals, which they can never pass. If one favoured individual be selected for a special education, some additional share of intelligence may, perhaps, with infinite pains, be infused; but the improvement perishes with that individual, and is wholly lost to the race. By far the greater portion of that knowledge which it imports them to possess is the gift of nature, who has wisely implanted such instinctive impulses as are necessary for their preservation. Man, also, is born with instincts, but they are few in number, compared with those

* All the parts met with in the brain of animals exist also in the brain of man; while several of those found in man are either extremely small, or altogether absent in the brains of the lower animals. Soemmering has enumerated no less than fifteen material anatomical differences between the human brain and that of the ape.

of the lower animals; and, unless cultivated and improved by reason and education, would, of themselves, produce but inconsiderable results. That of which the effects are most conspicuous, and which is the foundation of all that is noble and exalted in our nature, is the instinct of *Sympathy*. The affections of the lower animals, even between individuals of the same species, are observable only in a few instances; for in general they are indifferent to each other's joys or sufferings, and regardless of the treatment experienced by their companions. The attachment, indeed, of the mother to her offspring, as long as its wants and feebleness require her aid and protection, is as powerful in the lower animals, as in the human species; but its duration, in the former case, is confined, even in the most social tribes, to the period of helplessness; and the animal instinct is not succeeded, as in man, by the continued intercourse of affection and kind offices, and those endearing relations of kindred, which are the sources of the purest happiness of human life.

While Nature has, apparently, frowned on the birth of man, and brought him into the world weak, naked, and defenceless, unprovided with the means of subsistence, and exposed on every side to destruction, she has, in reality, implanted in him the germ of future greatness. The helplessness of the infant calls forth the fostering care and tenderest affections of the mother, and lays the deep foundations of the social union. The latent energies of his mind and body are successively, though slowly developed. While the vital organs are actively engaged in the execution of their different offices, while the digestive apparatus is exercising its powerful chemistry, while myriads of minute arteries, veins, and absorbents are indefatigably at work in building and modelling this complex frame, the sentient principle is no less assiduously and no less incessantly employed. From the earliest dawn of sensation it is ever busy in arranging, in combining, and in strengthening the impressions it receives. Wonderful as is the formation of the bodily fabric, and difficult as it is to collect its history, still more marvellous is the progressive construction of the human mind, and still more arduous the task of tracing the finer threads which connect the delicate web of its ideas, which fix its fleeting perceptions, and which establish the vast system of its associations, and of following the long series of gradations by which its affections are expanded, purified, and exalted, and the soul prepared for its higher destination in a future stage of existence.

Here, indeed, we perceive a remarkable interruption to that regular gradation, which we have traced in all other parts of the animal series; for between man and the most sagacious of the brutes there intervenes an immense chasm, of which we can hardly estimate the magnitude. The functions which are purely vital, and are necessary for even the lowest degree of sensitive existence, are possessed equally by all animals: in the distribution of the faculties of mere sensation a greater inequality may be perceived: the intellectual faculties, again, are of a more refined and nobler character, and being less essential to animal life, are dealt out by nature with a more sparing and partial hand. Between the two extremities of the scale we find an infinite number of intermediate degrees. The more exalted faculties are possessed exclusively by man, and constitute the source of the immense superiority he enjoys over the brute creation, which so frequently excels him in the perfection of subordinate powers. In strength and swiftness he is surpassed by many quadrupeds. In vain may he wish for the power of flight possessed by the numerous inhabitants of air. He may envy that range of sight which enables the bird to discern from a height at which it is itself invisible to our eyes, the minutest objects on the surface of the earth. He may regret the dulness of his own senses, when he adverts to the exquisite scent of the hound, or the acute hearing of the bat. While the delicate perceptions of the lower animals teach them to seek the food which is salutary, and avoid that which is injurious, man alone seems stinted in his powers of discrimination, and is compelled to gather instruction from a painful and hazardous experience. But if nature has created him thus apparently helpless, and denied him those instincts with which she has so liberally furnished the rest of her offspring, it was only to confer upon him gifts of infinitely higher value. While in acuteness of sense he is surpassed by inferior animals, in the powers of intellect he stands unrivalled. In the fidelity and tenacity with which impressions are retained in his memory, in the facility and strength with which they are associated, in grasp of comprehension, in extent of reasoning, in capacity of progressive improvement, he leaves all other animals at an immeasurable distance behind. He alone enjoys in perfection the gift of utterance; he alone is able to clothe his thoughts in words; in him alone do we find implanted the desire of examining every department of nature, and the power of extending his views beyond the confines of this globe. On him alone have the high privileges been bestowed of recognising and of adoring the Power, the Wisdom, and the Goodness of the Author of the Universe, from whom his being has emanated, to whom he owes all the blessings which attend it, and by whom he has been taught to look forward to brighter skies and to purer and more exalted conditions of existence. Heir to this high destination, Man discards all alliance with the beasts that perish; confiding in the assurance that the dissolution of his earthly frame destroys not the germ of immortality which has been implanted within him, and by the development of which the great scheme of Providence here commenced, will be carried on, in a future state of being, to its final and perfect consummation.

PART IV.

THE REPRODUCTIVE FUNCTIONS.

CHAPTER I.

REPRODUCTION.

LIMITS have been assigned to the duration of all living beings. The same power to whom they owe their creation, their organization, and their endowments, has also subjected them to the inexorable *Law of Mortality;* and has ordained that the series of actions which characterize the state of life, shall continue for a definite period only, and shall then terminate. The very same causes which, at the earlier stages of their existence, promoted their development and growth, and which at a maturer age, sustained the vigour and energies of the system, produce, by their continued and silent operation, gradual changes in the balance of the functions, and, at a later period, effect the slow demolition of the fabric they had raised, and the successive destruction of the faculties they had originally nurtured and upheld.* With the germs of life, in all organized structures, are conjoined the seeds of decay and of death; and however great may be the powers of their vitality, we know that those powers are finite, and that a time must come when they will be ex-

* See the article "AGE," in the *Cyclopædia of Practical Medicine,* where I have enlarged on this subject.

pended, and when their renewal, in that individual, is no longer possible.

But although the individual perishes, Nature has taken special care that the race shall be constantly preserved, by providing for the production of new individuals, each springing from its predecessor in endless perpetuity. The process by which this formation, or rather this apparent creation, of a living being is effected, surpasses the utmost powers of the human comprehension. No conceivable combinations of mechanical, or of chemical powers, bear the slightest resemblance, or the most remote analogy, to organic reproduction, or can afford the least clew to the solution of this dark and hopeless enigma. We must be content to observe and generalize the phenomena, in silent wonder at the marvellous manifestation of express contrivance and design, exhibited in this department of the economy of created beings.

Throughout the whole, both of the vegetable and animal world, Nature has shown the utmost solicitude to secure not only the multiplication of the species, but also the dissemination of their numbers over every habitable and accessible region of the globe, and has pursued various plans for the accomplishment of these important objects.

The simplest of all the modes of multiplication consists in the spontaneous division of the body of the parent into two or more parts; each part, when separated, becoming a distinct individual, and soon acquiring the size and shape of the parent. We meet with frequent examples of this process of *fissiparous generation*, as it is termed, among the infusory animalcules. Many species of *Monads*, for instance, which are naturally of a globular shape, exhibit at a certain period of their development a slight circular groove round the middle of their bodies, which by degrees becoming deeper, changes their form to that of an hour-glass; and the middle part becoming still more contracted, they present the appearance of two balls, united by a mere point. The monads in this state are seen swimming irregularly in the fluid, as if animated by two different volitions; and, apparently for the purpose of tearing asunder the last connecting fibres, darting through the thickest of the crowd of surrounding animalcules; and the moment this slender ligament is broken, each is seen moving away from the other, and beginning its independent existence. This mode of separation is illustrated by Fig. 462, representing the successive changes of form during this progress. In this animalcule the division is transverse, but in others, for example in the

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Vorticella, (as shown in Fig. 463,) and in most of the larger species, the line of separation is longitudinal. Each animalcule, thus formed by the subdivision of its predecessor, soon grows to the size which again determines a farther spontaneous subdivision into two other animalcules; these, in course of time, themselves undergo the same process, and so on, to an indefinite extent. The most singular circumstance attending this mode of multiplication is, that it is impossible to pronounce which of the new individuals thus formed out of a single one should be regarded as the parent, and which as the offspring, for they are both of equal size. Unless, therefore, we consider the separation of the parts of the parent animal to constitute the close of its individual existence, we must recognise an unbroken continuity in the vitality of the animal, thus transmitted in perpetuity from the original stem, throughout all succeeding generations. This, however, is one of those metaphysical subtleties for which the subject of reproduction affords abundant scope, but which it would be foreign to the object of this work to discuss.

It is in the animal kingdom only that we meet with instances of this spontaneous division of an organic being into parts; where each reproduces an individual of the same species. All plants, however, are capable of being multiplied by artificial divisions of this kind; thus, a tree may be divided longitudinally into a great number of portions, or *slips*, as they are called; any one of which, if planted separately and supplied with nourishment, may continue to grow, and may, in time, reproduce a tree similar in all respects to the one from which it originated. This inherent power of reproduction exists even in smaller fragments of a plant; for, when all circumstances are favourable, a stem will shoot from the upper end of the fragment, and roots will be sent forth from its lower end; and, ultimately, a complete plant will be formed.* These facts, which are well known to horticulturists, exhibit only the capabilities of vegetative power under circumstances which do not occur in the natural course of things, but have been the effect of human interference.

Reproductive powers of a similar kind are exhibited very extensively in the lower departments of the animal kingdom. The *Hydra*, or fresh water polype, is capable of indefinite multiplication by simple division: thus, if it be cut asunder transversely, the part containing the head soon supplies itself with a tail; and the detached tail soon shoots forth a new head, with a new set of tentacula. If any of the tentacula, or any portion of one of them, be cut off, the mutila-

* Among the conditions necessary for these evolutions of organs are, first, the previous accumulation of a store of nourishment in the detached fragment adequate to supply the growth of the new parts; and, secondly, the presence of a sufficient quantity of circulating sap, as a vehicle for the transmission of that nourishment. It has been found that when these conditions are present, even the leaf of an orange tree, when planted in a favourable soil, sends down roots, and is capable of giving origin to an entire tree. According to the observations of Mirandola, the leaf of the *Bryophyllum*, when simply laid on moist ground, strikes out roots, which quickly penetrate into the soil. (De Candolle, Physiologie Végétale, ii. 677.) The leaves of the monocotyledonous plants often present the same phenomenon.

tion is soon repaired; and if the whole animal be divided into a greater number of pieces, each fragment acquires, in a short time, all the parts which are wanting to render it a complete individual. The same phenomena are observed, and nearly to the same extent, in the *Planaria*. The *Asterias*, the *Actinia*, and some of the lower species of Annelida, as the *Nais*, are also capable of being multiplied by artificial divisions, each segment having the power of supplying others, and containing within itself a kind of separate and individual vitality.

A power of more partial regeneration of mutilated parts by new growths, which is very analogous to that of complete reproduction, exists in the higher orders of animals, though it does not extend to the entire formation of two individuals out of one. The claws, the feet, and the antennæ of the *Crustacea* and the limbs of the *Arachnida*, are restored, when lost, by a fresh growth of these organs. If the head of a *Snail* be amputated, the whole of that part of the animal, including the telescopic eyes, and other organs of sense, will be reproduced. Even among the Vertebrata we find instances of these renovations of mutilated parts; as happens with respect to the fins of fishes: for Brousonnet found that in whatever direction they are cut, the edges easily unite; and the rays themselves are reproduced, provided the smallest part of their base has been left. The tails of *Newts* and of some species of Lizards, will grow again, if lost; and what is more remarkable, the eyes themselves, with all their complex apparatus of coats and humours, will, if removed, be replaced by the growth of new eyes as perfect as the former. We have seen that the teeth of *Sharks* and other fishes are renewed with the utmost facility, when by accident they have been lost. Among Mammalia, similar powers exist, although they are restricted within much narrower limits; as is exemplified in the formation of new bones, replacing those which have perished. When we advert to the numberless instances of the reparation of injuries happening to various parts of our own frame, we have abundant reason to admire and be grateful for the wise and bountiful provisions which nature has made for meeting these contingencies.

The multiplication of the species by buds, or *Gemmiparous reproduction*, is exemplified on the largest scale in the vegetable creation. Almost every point of the surface of a plant appears to be capable of giving rise to a new shoot, which, when fully developed, exactly resembles the parent stock, and may, therefore, be regarded as a separate organic being. The origin of buds is wholly beyond the sphere of our observation; for they arise from portions of matter too minute to be cognizable to our organs, with every assistance which the most powerful microscopes can supply. These imperceptible atoms, from which organic beings take their rise, are called *germs*.

Vegetable germs are of two kinds; those which produce *stems*, and those which produce *roots;* and although both may be evolved from every part of the plant, the former are usually developed at the *axillæ* of the leaves; that is, at the angles of their junction with the stem; and also at the extremities of the fibres of the stems; their development being determined by the accumulation of nourishment around them. They first produce *buds*, which expanding, and putting forth roots, assume the form of shoots; and the successive accumulation of shoots, which remain attached to the parent plant,* and to each other, is what constitutes a tree. What are called knots in wood are the result of germs, which, in consequence of the accumulation of nourishment around them, are developed to a certain extent, and then

* In some rare instances the shoots are removed to a distance from the parent plant, by a natural process: this occurs in some creeping plants, which propagate themselves by the horizontal extension of their branches on the ground, where they dip, and strike out new roots, giving rise to stems independent of the original plant. This also sometimes happens in the case of tuberous roots, as the potato, which contain a number of germs, surrounded by nutritive matter, ready to be developed when circumstances are favourable. These portions are called *eyes;* and each of them, when planted separately, are readily evolved, and give rise to an individual plant.

cease to grow. The *Lemna*, or common Duckweed, which consists of a small circular leaf, floating on the surface of stagnant pools, presents a singular instance of the development of germs from the edges of the leaves, and the subsequent separation of the new plant thus formed. In this respect the process is analogous to the natural mode of multiplication met with in the lower orders of Zoophytes, such as the *Hydra*. At the earliest period at which the young of this animal is visible, it appears like a small tubercle, or bud, rising from the surface of the parent hydra: it grows in this situation, and remains attached for a considerable period; at first deriving its nourishment, as well as its mechanical support, from the parent; then occasionally stretching forth its tentacula, and learning the art of catching and of swallowing its natural prey. The tube, which constitutes its stomach, at first communicates by a distinct opening with that of its parent: but this opening afterwards closes; and the filaments by which it is connected with the parent becoming more and more slender, at length break, and the detached hydra immediately moves away, and commences its career of independent existence. This mode of multiplication, in its first period, corresponds exactly with the production of a vegetable by buds; and may therefore be classed among the instances of gemmiparous reproduction; although at a later stage, it differs from it in the complete detachment of the offspring from the parent.

Another plan of reproduction is that in which the germs are developed in the interior of the animal, assuming, at the earliest period when they become animated, the form of the parent. In this case they are termed *gemmules* instead of buds. This mode of reproduction is exemplified in the *Volvox*, which, as we have already seen, is an infusorial animalcule of a spherical form, exhibiting incessant revolving movements.* The germs of this animal are developed, in great numbers, in its interior, having a globular shape, and visible

* Vol. i. p. 139. This animal is delineated in Fig. 79.

by the aid of the microscope, through the transparent covering; and while yet retained within the body of the parent, other still minuter globules are developed within these, constituting a third generation of these animals. After a certain period, the young, which have thus been formed, escape by the bursting of the parent volvox, which, in consequence, perishes. Similar phenomena are presented by many of the Infusoria. In some of the Entozoa, likewise, as in the *Hydatid*, the young are developed within the parent; and this proceeds successively for an indefinite number of generations.* In most cases of the spontaneous evolution

* The mode in which infusory animalcules are produced and multiplied is involved in much obscurity. Many distinguished naturalists, adopting the views of Buffon, have regarded them as the product of an inherent power belonging to a certain class of material particles, which, in circumstances favourable to its operation, tends to form these minute organizations, and in this manner they explain how the same organic matter which had composed former living aggregates, on the dissolution of their union, reappears under new forms of life, and gives rise to the phenomenon of innumerable animalcules, starting into being, and commencing a new, but fleeting career of existence. Yet the analogy of every other department of the animal and vegetable kingdoms is directly opposed to the supposition that any living being can arise without its having been originally derived from an individual of the same species as itself, and of which it once formed a part. The difficulty which the hypothesis of the spontaneous production of infusory animalcules professes to remove, consists in our inability to trace the pre-existence of the germs in the fluid, where these animalcules are found to arise; and to follow the operations of nature in these regions of infinite minuteness. The discoveries of Ehrenberg relative to the organization of the *Rotifera* go far towards placing these diminutive beings more on a level, both in structure and in functions, with the larger animals, of whose history and economy we have a more familiar and certain knowledge, and in superseding the hypothesis above referred to, by showing that the bold assumption on which it rests, is not required for the explanation of the observed phenomena. In many of these animalcules, he has seen the ova excluded in the form of extremely minute globules, the 12,000th of an inch in diameter. When these had grown to the size of the 1700th of an inch, or seven times their original diameter, they were distinctly seen to excite currents, and to swallow food. The same diligent observer detected the young of the *Rotifer vulgaris*, perfectly formed, moving in the interior of the parent animalcule, and excluded in a living state, thus constituting them viviparous animals, as the former were

of gemmules within the parent, channels are provided for their exit: but the gemmules of the *Actinia* force their way through the sides of the body, which readily open to give them passage; after which, the lacerated part soon heals.

In the instances which have now passed under our review, the progeny is, at first, in direct communication with its parent, and does not receive the special protection of membranous envelopes, containing a store of nourishment for its subsequent growth. But in all the more perfect structures, both of animals and vegetables, the germ is provided with auxiliary coverings of this kind, the whole together composing what is called a *seed*, or an *ovum;* the former term being usually applied to vegetable, and the latter to animal productions; and, in both cases, the organ which originally contained them is termed the *ovary*.

The formation and evolution of vegetable seeds take place, not indiscriminately, at every point, as we have seen is the case with simple germs, but only in particular parts of the plant. The *Filices*, or fern tribes, may be taken as examples of this mode of reproduction, the seeds being formed at the under surface of the leaves, apparently by a simple process of evolution; and when detached and scattered on the ground, being farther developed into a plant similar to the parent. The Linnean class of *Cryptogamia* includes all the plants coming under this description. In Animals, likewise, it is only in the particular organs termed *ovaries*, that ova are formed, and they are generally divided into compartments, the whole being enclosed in a membranous covering, bearing a great resemblance to the *seed-capsules* of plants.

The propagation of living beings by means of ova or seeds, is a process of a totally different class from their multiplication by mere slips or buds; and the products of the former

oviparous. Other species, again, imitate the hydra, in being what is termed *gemmiparous*, that is, producing gemmules (like the budding of a plant,) which shoot forth from the side of the parent, and are soon provided with cilia, enabling them, when separated, to provide for their own subsistence, although they are of a very diminutive size when thus cast off.

retain less of the peculiar characters of the individual from which they spring, than those of the latter. This is remarkably exemplified in the case of orchard trees, such as apples and pears; for all the trees which derive their origin from shoots, or grafts from the same individual, partake of the same properties, and produce a fruit of nearly the same flavour and qualities; whereas, trees of the same species, which grow from seed, have the characters of distinct individuals, and losing all the peculiarities that may have distinguished the parent, revert to the original type of the species to which they belong. Thus, from the seeds of the golden pippin, or nonpareil, arise trees bearing the common crab apple, which is the natural fruit of the species. By continued graftings, after a long period, the vitality of the particular variety is gradually exhausted, and the grafts no longer bear the same fruit. This has already happened with regard to the two varieties of apples just mentioned. For these curious facts, and the theory which explains them, we are indebted to the observation and sagacity of Mr. Andrew Knight.*

The plans hitherto noticed are suited only to the simplest of vegetable or animal beings; but for the continuance of the higher races in both kingdoms of nature there is required a more complex procedure. The latent germ, contained in the seed or ovum, is never developed beyond a certain point, unless it be vivified by the action of a peculiar fluid, which is the product of other organs. Thus, there are established two distinct classes of structures; the office of the one being the formation of the seed or ovum, and that of the other the production of the vivifying fluid. The effect of this vivifying fluid upon the dormant germ is termed *Fecundation;* and the germ, when fecundated, receives the name of *Embryo.*

The modes in which the fecundation of the germ is accomplished are exceedingly various in different classes of organized beings. In all *Phanerogamous plants,* (so named

* See his various papers in the Philosophical Transactions.

in contradistinction to those which are *Cryptogamous*,) the whole of the double apparatus required for reproduction is contained in the *flower*. One set of organs contains the rudiment of the seed, enclosed in various envelopes, of which the assemblage constitutes an ovary, and to which is appended a tube, (the *pistil*,) terminated by a kind of spongiole, (the *stigma*.) The fecundating organs are the *stamens*, which are columns, (or *filaments*,) placed generally near and parallel to the pistil, and terminated by a glandular organ, (the *anther*.) This organ, when mature, contains, enclosed in a double envelope, a fine powder, (the *pollen*,) consisting of very minute vesicles, filled with a viscous liquor, (the *fovilla*,) in which are seen extremely small granules. Fecundation takes place by a portion of the pollen being received by the stigma, and conveyed through the tubular pistil to the seed, which it impregnates by imparting to it the fluid it contains.

By far the greater number of plants composing the vegetable kingdom have these two sets of organs contained in the same flower; or at least in flowers belonging to the same individual plant. In the animal kingdom this arrangement is also adopted, but only in a comparatively small number of tribes. In these the ova, in their passage from the ovary, along a canal termed the *oviduct*, are fecundated by receiving a secretion from another set of organs in the same system, which is conveyed by a duct, opening into the oviduct in some part of its course. In a limited number of plants, composing the class *Dioecia*, the individuals of the same species are distinguished by their bearing flowers which contain only one of the kinds of reproductive apparatus; so that the stamens and the pistils are situated on separate plants; and the impregnation of the ovaries in the latter, can be effected only by the transference of the pollen from the former. A similar separation of offices is established among all the higher classes of the animal kingdom. In most Fishes, and in all Batrachian reptiles, the ova are impregnated after their expulsion from the body: in all other cases their impregnation is internal, and their subsequent development takes place in one or other of the four following ways.

1. The ovum, when defended by a firm envelope, which contains a store of nutriment, is termed an *egg*, and is deposited in situations most favourable for the development of the embryo; and also for its future support when it emerges from the egg. Birds, as is well known, produce eggs which are incased in a calcareous shell, and hatch them by the warmth they communicate by sitting on them with unwearied constancy. All animals which thus lay eggs are termed *oviparous*.

2. There are a few tribes, such as the *Viper* and the *Salamander*, whose eggs are never laid, but are hatched in the interior of the parent; so that they bring forth living offspring, although originally contained in eggs. Such animals are said to be *Ovo-viviparous*. There are other tribes, again, which, according to circumstances, are either oviparous, or ovo-viviparous: this is the case with the *Shark*.

3. *Viviparous* animals are those in which no egg, properly so called, is completed; but the ovum, after proceeding through the oviduct, sends out vessels, which form an attachment to the interior of a cavity in the body of the parent, whence it draws nourishment, and therefore has attained a considerable size at the time of its birth.

4. *Marsupial* animals are those, which, like the *Kanguroo*, and the *Opossum*, are provided with abdominal pouches, into which the young, born at a very early stage of development, are received, and nourished with milk, secreted from glands contained within these pouches. As the young, both in this and in the last case, are nourished with milk prepared by similar glands, or *Mammæ*, the whole class of viviparous and marsupial animals has received, from this characteristic circumstance, the name of *Mammalia*.

CHAPTER II.

ORGANIC DEVELOPMENT.

Although the study of organic structures in their finished state must tend to inspire the most sublime conceptions of the Great Creator of this vast series of beings, extending from the obscurest plant to the towering tenant of the forest, and from the lowest animalcule to the stately elephant and gigantic whale, there yet exists another department of the science of Nature, removed, indeed, from the gaze of ordinary observers, but presenting to the philosophic inquirer subjects not less replete with interest, and not less calculated to exalt our ideas of the transcendent attributes of the Almighty. To a mind nurtured to reflection, these divine attributes, whether of power, of wisdom, or of beneficence, are no where manifested with greater distinctness, or arrayed in greater glory, than in the formation of these various beings, and in the progressive architecture of their wondrous fabric.

Our attention has already been directed, in a former part of these inquiries, to the successive changes, which constitute the metamorphoses of winged insects,* and of Batrachian reptiles, phenomena which are too striking to have escaped the notice of the earliest naturalists: but the patient investigations of modern inquirers have led to discoveries still more curious, and have shown that all vertebrated animals, even those belonging to the higher classes, such as birds, and mammalia, not excepting man himself, undergo, in the early stages of their development, a series of changes fully as great and as remarkable as those which constitute the

* The Researches of Nordmann, on different species of *Lernæa*, have brought to light the most singular succession of forms during the progress of development of the same individual animal.

transformations of inferior animals. They have also rendered it extremely probable that the organs of the system, instead of existing simultaneously in the germ, arise in regulated succession, and are the results not of the mere expansion of pre-existing rudiments, but of a real formation by the union of certain elements; which elements are themselves successively formed by the gradual coalescence or juxtaposition of their constituent materials. On contemplating the infinitely lengthened chain of means and ends, and of causes and effects, which, during the construction and assemblage of the numerous parts composing the animal machine, are in constant operation, adapting them to their various purposes, and combining them into one efficient and harmonious system, it is impossible not to be deeply impressed with the extent and the profoundness of the views of Providence, which far exceed the utmost boundaries of our vision, and surpass even the powers of the human imagination.*

The clearest evidence of enlarged and provident designs may be collected from observing the order in which the nascent organs are successively brought forwards, and added to the growing fabric: such order appearing, in all cases, to be that best calculated to secure the due performance of their appointed functions, and to promote the general objects of the system. The apparatus first perfected is that which is immediately necessary for the exercise of the vital functions, and which is therefore required for the completion of all the other structures; but provision is likewise made for the esta-

* "Si l'on applique," says Cuvier, when speaking of the anatomy of insects, "à chacune de ces espèces, par la pensée, ce qu'il seroit bien impossible qu'un homme entreprit de vérifier en effet pour toutes, une organisation à-peu-près égale en complication à celle qui a été décrite dans la chenille par Lyonet, et tout récemment dans le hanneton par M. Straus, et cependant plus ou moins differente dans chaque insecte, l'imagination commencera à concevoir quelque chose de cette richesse effrayante, et de ces millions de millions de parties, et de parties de parties, toujours corrélatives, toujours en harmonie, qui constituent le grand ouvrage de la nature." (Histoire des Progrès des Sciences Naturelles, iv. 145.)

blishment of those parts which are to give mechanical support to each organic system in proportion as it is formed; while the foundations are also preparing for endowments of a higher kind, by the early development of the organs of the external senses, the functions of which so essentially minister to the future expansion of the intellectual faculties, embracing a wide range of perceptions and of active powers. Thus, in the early, as well as in all the subsequent periods of life, the objects of nature vary as the respective necessities of the occasion change. At first, all the energies of vitality are directed to the raising of the fabric, and to the extension of those organs which are of greatest immediate utility; but still having a prospective view to farther and more important ends. For the accomplishment of this primary object, unremitting exertions are made, commensurate with the magnitude of the design, and giving rise to a quick succession of varied forms, both with regard to the shape of each individual organ, and to the general aspect of the whole assemblage.

In the phenomena of their early evolution, Plants and Animals present a striking contrast, corresponding to essential differences in the respective destinations of these two orders of beings. The primary object of vegetable structures appears to be the establishment of the functions of nutrition; and we accordingly find that whenever the seed begins to germinate, the first indication of development is the appearance of the part called the *plumula*, which is a collection of feathery fibres, bursting from the enveloping capsule of the germ, and which, whatever may have been its original position, proceeds immediately to extend itself vertically; while, at the same time, slender filaments, or *radicles*, shoot out below to form the roots. Thus early are means provided for the absorption and the aeration of the nutrient matter, which is to constitute the materials for the subsequent growth of the plant, and for the support and protection of the organs by which these processes are to be carried on. But animal vitality, being designed to minister to a higher order of endowments, is placed in subordination to a class of functions, of which there exists no trace in vegetables, namely, those of the nervous system. By attentively watching the earliest dawn of organic formation, in the transparent gelatinous molecule, for example, which, with its three investing pellicles, constitutes the embryo of a bird, (for the eggs of this class of animals best admit of our following this interesting series of changes,) the first opaque object discoverable by the eye is a small dark line, called the primitive trace, formed on the surface of the outermost pellicle. Two ridges then arise, one on each side of this dark line;* and by the union of their edges, they soon form a canal, containing a deposite of semi-fluid matter, which, on acquiring greater consistence and opacity, discloses two slender and delicate threads, placed side by side, and parallel to one another, but separated by a certain space. These are the rudiments of the spinal cord, or the central organ of nervous power, on the endowments of which the whole character of the being to be formed depends. We may next discern a number of parallel equidistant dots, arranged in two rows, one on the outer side of each of the filaments already noticed: these are the rudiments of the vertebræ, parts which will afterwards be wanted for giving protection to the spinal marrow, and which soon form, for this purpose, a series of rings embracing that organ.†

The appearance of the elementary filaments of the spinal cord is soon followed by the development of its upper or anterior extremity, from which there arise three vesicles, each forming white tubercles; these are the foundations of the future brain. The tubercles are first arranged in pairs and in a longitudinal series, like those we have seen constituting the permanent form of the brain in the inferior fishes:

* The *plicæ primitivæ* of Pander; the *laminæ dorsales* of Baer. See a paper on embryology by Dr. Allan Thomson, in the Edin. New Phil. Journal for 1830 and 1831.

† These rings have, by speculative physiologists, been supposed to be analogous to those which form the skeleton of the Annelida.

but, in birds, they are soon folded together into a rounded mass; while, in the mean time, the two filaments of the spinal cord have approached each other, and united into a single column, the form which they ever after retain. Even at this early period the rudiments of the organs of the higher senses, (first of the eye, and next of the labyrinth of the ear,) make their appearance; but, on the other hand, those of the legs and wings do not show themselves until the brain has acquired greater solidity and development. The nerves which are to connect these organs of sensation and of motion with the spinal cord and brain are formed afterwards, and are successively united to the nervous centres.

Although the plan of the future edifice has thus been sketched, and its foundations laid in the homogeneous jelly by the simpler efforts of the vital powers, the elevation of the vast superstructure demands the aid of other machinery, fitted to collect and distribute the requisite materials. Here, then, we might, perhaps, expect to meet with a repetition of those vegetative processes, having similar objects in view, and the adoption of analogous means for their accomplishment; but so widely different in character is the whole organic economy of these two orders of beings, that we perceive no resemblance in the mechanism employed for their formation. For the purposes of animal life the nutrient juices must be brought into active circulation by means of vessels extensively pervading the system. Nature, then, hastens to prepare this important hydraulic apparatus, without which the work of construction could not proceed. What may be the movements of the transparent nutrient juices at the very earliest period must, of course, remain unknown to us, since we can only follow them by the eye after the nutritive substance they contain has become consolidated in the form of opaque globules. These globules are at first seen to meander through the mass, unconfined by investing vessels; presently, however, a circular vessel is discovered, formed by the foldings of the membrane of the embryo, along which the fluids undulate backwards and forwards, without any constancy.* A delicate net-work of vessels is next formed in various parts of the area of the circle, which are seen successively to join by the formation of communicating branches, and ultimately to compose larger trunks, so as to establish a more general system of vascular organization. But increased power for carrying on this extended circulation will soon be wanted; and for this purpose there must be provided a central organ of propulsion, or heart, the construction of which is now commenced, at a central point, by the folding inwards of a lamina of the middle membrane, forming first a simple groove, but, after a time, converted, by the union of its outer edges, into a kind of sac, which is soon extended into a longitudinal tube.† The next object is to bring this tube, or rudimental heart, into communication with the neighbouring vascular trunks, and this is effected by their gradual elongation, till their cavities meet, and are joined; one set of trunks (the future veins,) first uniting with the anterior end of the tube; and then another set (the future arteries,) joining its other end. The addition of this central tube to the vessels previously formed completes the continuity of their course; so that the uniform circulation of the blood is established in the direction in which it is ever after to flow; and we may now recognise this central organ as the heart, which, under the name of the *punctum saliens*, testifies by its quick and regular pulsations that it has already begun to exercise its appropriate function. It is long, however, before it acquires the form which it is permanently to retain; for from being at first a mere lengthened tube, presenting three dilatations, which are the cavities of the future auricle, ventricle, and bulb of the aorta, it assumes in process of time a rounded shape, by the folding of its parts, the whole of

* These phenomena are similar to those which were noticed as presented by the larvæ of some insects and other inferior animals.

† The discovery of this fact is due to Pander. See also the works of Rolando, Wolff, Prevost and Dumas, and Serres.

which are coiled, as it were, into a knot; by which means the different cavities acquire relative situations more nearly corresponding to their positions in the developed and finished organ.

The blood-vessels, in like manner, undergo a series of changes quite as considerable as those of the heart, and totally altering their arrangement and distribution. Serres maintains that the primitive condition of all the organs, even those which are generally considered as single, is that of being double, or being formed in pairs; one on the right, and another exactly similar to it on the left of the middle, or *mesial* plane, as if each were the reflected image of the other.* Such is obviously the permanent condition of all the organs of sensation, and also of the apparatus for locomotion; and it has just been shown that those portions of the nervous system which are situated in the mesial plane, such as the spinal cord and the brain, consisted originally of two separate sets of parts, which are brought together, and conjoined into single organs. In like manner we have seen that the constituent laminæ of the heart are at first double, and afterwards form, by their union, a single cavity. The operation of the same law has been traced in the formation of those vascular trunks, situated in the mesial plane, which are usually observed to be single, such as the aorta and the vena cava; for each were originally formed by the coalescence of double vascular trunks running parallel to each other, and at first separated by a considerable interval; then approaching each other, adhering together, and quickly converted,

* A remarkable exemplification of this tendency to symmetric duplication of organs occurs in a very extraordinary parasitic animal, which usually attaches itself to the gills of the *Cyprinus brama*, and which has been lately examined by Nordmann, and named by him the *Diplozoon paradoxum*, from its having the semblance of two distinct animals of a lengthened shape, each bent at an obtuse angle, and joined together in the form of the letter X. The right and left halves of this cross are perfectly similar in their organization, having each a complete and independent system of vital organs, excepting that the two alimentary canals join at the centre of the cross to form a single cavity, or stomach. (Annales des Sciences Naturelles, xxx. 373.)

by the obliteration of the parts which are in contact, into single tubes, throughout a considerable portion of their length.*

Nature, ever vigilant in her anticipations of the wants of the system, has accumulated round the embryo ample stores of nutritive matter, sufficient for maintaining the life of the chick, and for the building of its frame, while it continues in the egg, and is, consequently, unable to obtain supplies from without; yet, with the same foresight of future circumstances, she delays not, longer than is necessary for the complete establishment of the circulation, to construct the apparatus for digestion, on which the animal is to rely for the means of support in after life. The alimentary canal, of which no trace exists at an earlier period, is constructed by the formation of two laminæ, arising from folds of the innermost of the pellicles which invest the embryo; that is, on the surface opposite to the one which has produced the spinal marrow. These laminæ, which are originally separate, and apart from one another, are brought together, and by the junction or soldering of their opposite edges, formed into a tube,† which, from being, at first, uniform in diameter, afterwards expands into several dilated portions, corresponding with the cavities of the stomach, crop, gizzard, &c., into which they are to be converted, when the time shall come for their active employment. These new organs are, however, even in this, their rudimental state, trained to the performance of their proper offices, receiving into their cavities, through a tube temporarily provided for that purpose, the fluid of the yelk, and preparing nourishment from it.

In the mean time, early provision is made for the aeration of the fluids by an extensive but temporary system of

* These facts were first observed by Serres (Annales des Sc. Nat. xxi. 8,) and their accuracy has been confirmed by the observations of Dr. Allen Thomson. In Reptiles this union of the two constituent trunks of the aorta is effected only at the posterior part, while the anterior portion remains permanently double. (See Fig. 357, vol. ii. p. 197.)

† Wolff is the author of this discovery.

vessels, spread over the membrane of the egg, and receiving the influence of atmospheric oxygen through the substance of the shell, which is sufficiently porous to transmit it; and these vessels, being brought into communication with the circulatory system of the chick, convey to its blood this vivifying agent. As the lungs cannot come into use till after the bird is emancipated from its prison, and as it was sufficient that they should be in readiness at that epoch, these organs are among the last that are constructed; and as the mechanism of respiration in this class of animals does not require the play of the diaphragm, this muscular partition is only begun, but not completed, and there is no separation between the cavities of the thorax and the abdomen.

The succession of organic metamorphoses is equally remarkable in the formation of the diversified apparatus for aeration, which is required to be greatly modified, at different periods, in order to adapt it to different elements: of this we have already seen examples in those insects which, after being aquatic in their larva state, emerge from the water when they have acquired wings; and also in the steps of transition from the tadpole to the frog. But similar, though less conspicuous changes occur in the higher vertebrated animals, during the early periods of their formation, corresponding to the differences in the modes of aeration employed at different stages of development. In the primeval conditions this function is always analogous to that of aquatic animals, and requires for its performance only the simpler form of heart already described, consisting of a single set of cavities: but the system being ultimately designed to exercise atmospheric respiration, requires to be gradually adapted to this altered condition; and the heart of the Bird and the Quadruped must be separated into two compartments, corresponding to the double function it will have to perform. For this purpose a partition wall is built in its cavity; and this wall is begun around the interior circumference of the ventricle, and is gradually carried on towards the centre, there being, for a time, an aperture of communication between the right and left cavities; but this aperture is soon closed, and the ventricle is now effectually divided into two. Next the auricle, which at first was single, becomes double; not, however, by the growth of a partition, but by the folding in of its sides, along a middle line, as if it were encompassed by a cord, which was gradually tightened. In the mean while the partition, which had divided the ventricle, extends itself into the trunk of the main artery, which it divides into two channels; and these afterwards become two separate vessels; that which issues from the left ventricle being the aorta; and the other, which proceeds from the right ventricle, being the pulmonary artery; and each of these vessels is now prepared to exercise its appropriate function in the double circulation which is soon to be established.*

A mode of subdivision of blood vessels, very similar to that just described, takes place in those which are sent to the first set of organs provided for aeration, and which resemble branchiæ. These changes may be very distinctly followed in the *Batrachia*;† for we see, in those animals, the trunk of the aorta undergoing successive subdivisions by branches sent off from it, and forming loops, which extend in length, and are again subdivided, in a manner not unlike the unravelling of the strands of a rope; each subdivision, however, being preceded by the formation of a double partition in the cavity of the tube; so that at length the whole forms an extensive ramified system of branchial arteries and veins. Still all these are merely temporary structures; for when the period of change approaches, and the branchiæ are to be superseded in their office, every vessel, one after another, becomes obliterated, and there remain only the two original aortæ, which unite into a single trunk lower down, and from which proceed the pulmonary arteries, conveying either the whole, or a portion of the blood, to the newly developed respiratory organs, the lungs.

* The principal authorities for the facts here stated are Baer and Rolando. See the paper of Dr. Thomson already quoted.

† See the investigations of Rusconi, and of Baer, on this subject.

By a similar process of continued bifurcation, or the detachment of branches in the form of loops, new vessels are developed in other parts of the body, as has been particularly observed in the finny tail, and the external gills of the frog, and the newt, parts which easily admit of microscopical examination.*

Progress is in the mean while making in the building of the skeleton, the forms of the principal bones being modelled in a gelatinous substance, which is converted into cartilage, beginning at the surface, and gradually advancing towards the centre of each portion or element of the future bone; and thus a temporary solid and elastic scaffolding is raised, suited to the yielding texture of the nascent organs; lastly, the whole fabric is surrounded by an outer wall, the building of which is begun from the dorsal region, and conducted round the sides of the body, till the two portions come to meet in the middle abdominal line, where they are finally united into one general and continuous integument. The eyes, which were hitherto unprotected, receive special means of defence, by the addition of eyelids, which are formed by a farther extension and folding of these integuments; and the greater part of the surface of the body gives rise to a growth of temporary down, which, as we have seen, is provided as a covering to the bird at the time it is ready to quit the shell. But this hard shell, which had hitherto afforded it protection, is now opposed to its emancipation; and the chick, in order to obtain its freedom, must, by main force, break through the walls of its prison; its beak is, however, as yet too tender to apply the force requisite for that purpose. Here, again, we find nature expressly interposing her assistance; for she has caused a pointed horny projection to grow at the end of the beak, for the special object of giving the chick the power of battering its shell, and making a practicable breach, through which it shall be able to creep out, and begin its new career of life. That this horn is pro-

* Such is the result of the concurring observations of Spallanzani, Fontana, and Döllinger.

vided only for this temporary use appears from the circumstance of its falling off spontaneously in the course of three or four days after it has been so employed.

But though the bird has now gained its liberty, it is still unable to provide for its own maintenance, and requires to be fed by its parent till it can use its wings, and has learned the art of obtaining food. The pigeon is furnished by nature with a secretion from the crop, with which it feeds its young. In the Mammalia the same object is provided for still more expressly, by means of glands, whose office it is to prepare *milk*, a fluid which, from its chemical qualities, is admirably adapted to the powers of the digestive organs, when they first exercise their functions. The Cetacea have also mammary glands; but as the structure of the mouth and throat of the young in that class does not appear adapted to the act of sucking, there has always been great difficulty in understanding how they obtain the nourishment so provided. A recent discovery of Geoffroy St. Hilaire appears to have resolved the mystery with respect to the *Delphinus globiceps;* for he found that the mammary glands of that animal contain each a large reservoir, in which milk is accumulated, and which the dolphin is capable, by the action of the surrounding muscles, of emptying at once into the mouth of its young, without requiring from the latter any effort of suction.*

The rapid sketch which I have attempted to draw of the more remarkable steps of the early stages of organic development in the higher animals, taken in conjunction with the facts already adverted to in various parts of this Treatise, and particularly those relating to ossification, dentition, the formation of hair, of the quills of the porcupine, of the antlers of the stag, and of the feathers of birds, will suffice to show that they are regulated by laws which are definite, and preordained according to the most enlarged and profound

* The account of this discovery is contained in a memoir which was read at the "Institute." March 24, 1834.

views of the future circumstances and wants of the animal. The double origin of all the parts of the frame, even those which appear as single organs, and the order of their formation, which, in each system, commences with the parts most remote from the centre, and proceeds inwards, or towards the mesial plane, are among the most singular and unexpected results of this train of inquiries.* We cannot but be forcibly struck with the numerous forms of transition through which every organ has to pass before arriving at its ultimate and comparatively permanent condition: we cannot but wonder at the vast apparatus which is provided and put in action for effecting all these changes; nor can we overlook the instances of express contrivance in the formation of so many temporary structures, which are set up, like the scaffold of an edifice, in order to afford the means of transporting the materials of the building in proportion as they are wanted; nor refuse to recognise the evidence of provident design in the regular order in which the work proceeds, every organ growing at its appointed time, by the addition of fresh particles brought to it by the arteries, while others are carried away by the absorbents, and are gradually acquiring the form which is to qualify it for the performance of its proper office in this vast and complicated system of animal life.

* The first of these two laws is termed by Serres, who has zealously prosecuted these investigations, "*la loi de symmétrie;*" and the second, "*la loi de conjugaison.*" He maintains that they are strictly applicable to all the parts of the body having a tubular form, such as the trachea, the Eustachian tube, the canals, and perforations of bones, &c. See the preliminary discourse to his "Anatomie comparée du cerveau," p. 25; and also his several memoirs in the "Annales des Sciences Naturelles," vols. xi. xii. xvi. and xxi.

An excellent summary of the principal facts relating to the development of the embryo is given by Mr. Herbert Mayo, in the third edition of his "Outlines of Human Physiology."

CHAPTER III.

DECLINE OF THE SYSTEM.

To follow minutely the various steps by which Nature conducts the individual to its state of maturity, would engage us in details incompatible with the limits of the present work. I shall only remark, in general, that during the period when the body is intended to increase in size, the powers of assimilation are exerted to prepare a greater abundance of nourishment, so that the average supply of materials rather exceeds the consumption: but when the fabric has attained its prescribed dimensions, the total quantities furnished and expended being nearly balanced, the vital powers are no longer exerted in extending the fabric, but are employed in consolidating and perfecting it, and in qualifying the organs for the continued exercise of their respective functions, during a long succession of years.

Yet, while every function is thus maintained in a state of healthy equilibrium, certain changes are in progress, which, at the appointed season, will inevitably bring on the decline and ultimate destruction of the system.* The process of

* It would appear, from the researches of De Candolle, that the vegetable system is not, like the animal, subject to the destructive operation of internal causes; for the agents which destroy vegetable life are always extraneous to its economy. Each individual tree is composed of an accumulation of the shoots of every successive year since the commencement of its growth; and although, from the continued deposition of lignin, and the consequent obliteration of many of its cells and vessels, the vitality of the interior wood may be destroyed, and it then becomes liable to decay by the action of foreign agents, yet the exterior layers of the *liber* still vegetate with undiminished vigour; and unless injured by causes extraneous to its own system, the life of the tree will continue to be sustained for an indefinite period. If, on the

consolidation, begun from the earliest period of development, is still advancing, and is prducing in the fluids greater thickness, and a reduction of their total quantity; and in the solids, a diminution in the proportion of gelatin, and the conversion of this element into albumen. Hence, all the textures acquire increasing solidity, the cellular substance becomes firmer and more condensed, and the solid structures more rigid and inelastic: hence, the tendons and ligamentous fibres growing less flexible, the joints lose their suppleness, and the contractile power being also impaired, the muscles act more tardily as well as more feebly, and the limbs no longer retain the elastic spring of youth. The bones themselves grow harder and more brittle; and the cartilages, the tendons, the serous membranes, and the coats of the blood vessels, acquire incrustations of ossific matter, which interfere with their uses. Thus are all the progressive modifications of structure tending, slowly but inevitably, to disqualify the organs for the due performance of their functions.

Among the most important of the internal changes consequent on the progress of age are those which take place in the vascular system. A large proportion of the numerous arteries, which were in full activity during the building of the fabric, being now no longer wanted, are thrown, as it were, out of employment; they, in consequence, contract, and becoming impervious, gradually disappear. The parts of the body, no longer yielding to the power applied to extend them, oppose a gradually increasing resistance to the propelling force of the heart; while, at the same time, this force, in common with all the others, is slowly diminishing. Thus do the vital powers become less equal to the demands made upon them; the waste of the body exceeds the supply,

other hand, we were to regard each separate shoot as an individual organic body, and every layer as constituting a distinct generation of shoots, the older being covered and enclosed in succession by the younger, the great longevity of a tree would, on this hypothesis, indicate only the permanence of the species, not the indefinitely protracted duration of the individual plant.

and a diminution of energy becomes apparent in every function.

Such are the insensible gradations by which, while gliding down the stream of time, we lapse into old age, which insidiously steals on us before we are aware of its approach. But the same provident power which presided at our birth, which superintended the growth of all the organs, which infused animation into each as they arose, and which conducted the system unimpaired to its maturity, is still exerted in adjusting the conditions under which it is placed in its season of decline. New arrangements are made, new energies are called forth, and new resources are employed, to accommodate it to its altered circumstances, to prop the tottering fabric, and retard the progress of its decay. In proportion as the supply of nutritive materials has become less abundant, a more strict economy is practised with regard to their disposal; the substance of the body is husbanded with greater care; the absorbent vessels are employed to remove such parts as are no longer useful; and when all these adjustments have been made, the functions still go on for a considerable length of time without material alteration.

The period prescribed for its duration being at length completed, and the ends of its existence accomplished, the fabric can no longer be sustained, and preparation must be made for its inevitable fall. In order to form a correct judgment of the real intentions of nature, with regard to this last stage of life, its phenomena must be observed in cases where the system has been wholly intrusted to the operation of her laws. When death is the simple consequence of age, we find that the extinction of the powers of life observes an order the reverse of that which was followed in their evolution. The sensorial functions, which were the last perfected, are the first which decay: and their decline is found to commence with those mental faculties more immediately dependent on the physical conditions of the sensorium, and more especially with the memory, which is often much impaired, while the judgment remains in full vigour. The next faculties which usually suffer from the effects of age are the external senses, and the failure of sight and of hearing still farther contributes to the decline of the intellectual powers, by withdrawing many of the occasions for their exercise. The actual demolition of the fabric commences whenever there is a considerable failure in the functions of assimilation; but the more immediate cause of the rapid extinction of life is usually the impediment which the loss of the sensorial power, necessary for maintaining the movements of the chest, creates to respiration. The heart, whose pulsations gave the first indications of life in the embryo, generally retains its vitality longer than any other organ; but its powers being dependent on the constant oxidation of the blood in the lungs, cannot survive the interruption of this function; and on the heart ceasing to throb, death may then be considered as complete in every part of the system.

It is an important consideration, with reference to final causes, that generally long before the commencement of this

"Last scene of all,
That ends this strange eventful history,"

the power of feeling has wholly ceased, and the physical struggle is carried on by the vital powers alone, in the absence of all consciousness of the sentient being, whose death may be said to precede, for some time, that of the body. In this, as well as in the gradual decline of the sensorial faculties, and the consequent diminution both of mental and of physical sensibility in advanced age, we cannot fail to recognise the wise ordinances of a superintending and beneficent Providence, kindly smoothing the path along which we descend the vale of life, spreading a narcotic mantle over the bed of death, and giving to the last moments of departing sensation the tranquillity of approaching sleep.

CHAPTER IV.

UNITY OF DESIGN.

THE inquiries on Animal and Vegetable Physiology in which we have been engaged, lead to the general conclusion that unity of design and identity of operation pervade the whole of nature; and they clearly point to one Great and only Cause of all things, arrayed in the attributes of infinite power, wisdom, and benevolence, whose mighty works extend throughout the boundless regions of space, and whose comprehensive plans embrace eternity.

In examining the manifold structures and diversified phenomena of living beings, we cannot but perceive that they are extensively, and perhaps universally connected by certain laws of *Analogy;* a principle, the recognition of which has given us enlarged views of a multitude of important facts, which would otherwise have remained isolated and unintelligible. Hence naturalists, in arranging the objects of their study, according to their similarities and analogies, into classes, orders and genera, have but followed the footsteps of Nature herself, who in all her operations combines the apparently opposite principles of general resemblance, and of specific variety; so that the races which she has united in the same group, though possessed of features individually different, may easily be recognised by their family likeness, as the offspring of a common parent.

> "Facies non omnibus una;
> Nec diversa tamen; qualem decet esse sororum."

We have seen that in each of the two great divisions, or kingdoms of organic nature, the same general objects are aimed at, and the same general plans are devised for their accomplishment; and, also, that in the execution of those plans similar means and agencies are employed. In each division there prevails a remarkable uniformity in the composition and properties of their elementary textures, in the nature of their vital powers, in the arrangement of their organs, and in the laws of their production and development. The same principle of analogy may be traced, amidst endless modifications of detail, in all the subordinate groups into which each kingdom admits of being subdivided, both in respect to the organization and functions of the objects comprehended in each assemblage, whether we examine the wonders of their mechanical fabric, or study the series of processes by which nutrition, sensation, voluntary motion, and reproduction are effected. To specify all the examples which might be adduced in confirmation of this obvious truth is here unnecessary; for it would be only to repeat the numerous facts already noticed in every chapter of this treatise, relative to each natural group of living beings; and it was, indeed, chiefly by the aid of such analogies, that we were enabled to connect and generalize those facts. We have seen that, in constructing each of the divisions so established, Nature appears to have kept in view a certain definite type, or ideal standard, to which, amidst innumerable modifications, rendered necessary by the varying circumstances and different destinations of each species, she always shows a decided tendency to conform. It would almost seem as if, in laying the foundations of each organized fabric, she had commenced by taking an exact copy of this primitive model; and, in building the superstructure, had allowed herself to depart from the original plan only for the purpose of accommodation to certain specific and ulterior objects, conformably with the destination of that particular race of created beings. Such, indeed, is the hypothetical principle, which, under the title of *unity of composition*, has been adopted and zealously pursued in all its consequences, by many naturalists, of the highest eminence, on the continent. As the facts on which this hypothesis is supported, and the views which it unfolds, are highly deserving of attention, I shall here briefly state them; but in so doing I shall beg to premise the caution that these views should, for the present, be regarded as hypothetical, and as by no means possessing the certainty of philosophical generalizations.

The hypothesis in question is countenanced, in the first place, by the supposed constancy with which, in all the animals belonging to the same natural group, we meet with the same constituent elements of structure, in each respective system of organs, notwithstanding the utmost diversity which may exist in the forms of the organs, and in the uses to which they are applied. This principle has been most strikingly exemplified in the osteology of vertebrated animals; but its truth is also inferred from the examination of the mechanical fabric of Insects, Crustacea, and Arachnida; and it appears to extend also to the structures subservient to other functions, and particularly those of the nervous system. Thus Nature has provided for the locomotion of the serpent, not by the creation of new structures, foreign to the type of the vertebrata, but by employing the ribs in this new office; and in giving wings to a lizard, she has extended these same bones to serve as supports to the superadded parts. In arming the elephant with tusks, she has merely caused two of the teeth in the upper jaw to be developed into these formidable weapons; and in providing it with an instrument of prehension, has only resorted to a greater elongation of the snout.

The law of *Gradation*, in conformity to which all the living, together with the extinct races, of organic nature, arrange themselves more or less, into certain regular series, is one of the consequences which have been deduced from the hypothesis we are considering. Every fresh copy taken of the original type is supposed to receive some additional extension of its faculties and endowments by the graduated development of elements, which existed in a latent form in the primeval germ, and which are evolved, in succession, as nature advances in her course. Thus, we find that each new form which arises, in following the ascending scale of creation, retains a strong affinity to that which had preceded it, and also tends to impress its own features on those which immediately succeed; and thus their specific differences result merely from the different extent and direction given to these organic developments; those of inferior races proceeding to a certain point only, and there stopping; while in beings of a higher rank they advance farther, and lead to all the observed diversities of conformation and endowments.

It is remarked, in farther corroboration of these views, that the animals which occupy the highest stations in each series possess, at the commencement of their existence, forms exhibiting a marked resemblance to those presented in the permanent condition of the lowest animals in the same series; and that, during the progress of their development, they assume, in succession, the characters of each tribe, corresponding to their consecutive order in the ascending chain; so that the peculiarities which distinguish the higher animal, on its attaining its ultimate and permanent form, are those which it has received in its last stage of embryonic evolution. Another consequence of this hypothesis is, that we may expect occasionally to meet, in inferior animals, with rudimental organs, which from their imperfect development may be of little or no use to the individual, but which become available to some superior species, in which they are sufficiently perfected. The following are among the most remarkable facts in illustration of these propositions.

In the series of Articulated Animals, of which the Annelida constitute the lowest, and winged Insects the highest terms, we find that the larvæ of the latter are often scarcely distinguishable, either in outward form, or in internal organization, from Vermes of the lower orders; both being equally destitute of, or but imperfectly provided with external instruments of locomotion; both having a distinct vascular circulation, and multiple organs of digestion; and the central filaments of the nervous system in both being studded with numerous pairs of equidistant ganglia. In the worm all these features remain as permanent characters of the order: in the insect they are subsequently modified and altered during its progressive metamorphoses. The embryo of a crab resembles in appearance the permanent forms of the *Myriapoda*, and of the lower animals of its own class, but acquires, in the progress of its growth, new parts; while those already evolved become more and more concentrated, passing, in their progress, through all the forms of transition which characterize the intermediate tribes of Crustacea; till the animal attains its last state, and then exhibits the most developed condition of that particular type.*

However different the conformations of the Fish, the Reptile, the Bird, and the warm-blooded quadruped, may be at the period of their maturity, they are scarcely distinguishable from one another in their embryonic state; and their early development proceeds for some time in the same manner. They all possess at first the characters of aquatic animals; and the Frog even retains this form for a considerable period after it has left the egg. The young tadpole is in truth a fish, whether we regard the form and actions of its instruments of progressive motion, the arrangement of its organs of circulation and of respiration, or the condition of the central organs of its nervous system. We have seen by what gradual and curious transitions all these aquatic characters are changed for those of a terrestrial quadruped, furnished with limbs for moving on the ground, and with lungs for breathing atmospheric air; and how the plan of circulation is altered from branchial to pulmonary, in proportion

* This curious analogy is particularly observable in the successive forms assumed by the nervous system, which exhibits a gradual passage from that of the *Tulitrus*, to its ultimate greatest concentration in the *Maia*. (See Figures 439 and 441, p. 382 and 383.) Milne Edwards has lately traced a similar progression of development in the organs of locomotion of the Crustacea. (Annales des Sciences Naturelles, xxx. 354.)

as the gills wither and the lungs are developed. If, while this change is going on, and while both sets of organs are together executing the function of aeration, all farther development were prevented, we should have an amphibious animal, fitted for maintaining life both in air and in water. It is curious that this precise condition is the permanent state of the *Siren* and the *Proteus*, animals which thus exemplify one of the forms of transition in the metamorphoses of the Frog.

In the rudimental form of the feet of serpents, which are so imperfectly developed as to be concealed underneath the skin, and to be useless as organs of progressive motion, we have an example of the first stage of that process, which, when carried farther in the higher animals, gives rise to the limbs of quadrupeds, and which it would almost seem as if nature had instituted with a prospective view to these more improved constructions. Another, and a still more remarkable instance of the same kind, occurs in the rudimental teeth of the young of the Whale, which are concealed within the lower jaw, and which are afterwards removed, to give place to the curious filtering apparatus, which occupies the roof of the mouth, and which nature has substituted for that of teeth, as if new objects, superseding those at first pursued, had arisen in the progress of development.

Birds, though destined to a very different sphere of action from either fishes or reptiles, are yet observed to pass, in the embryonic stage of their existence, through forms of transition, which successively resemble these inferior classes. The brain presents, in its earliest formation, a series of tubercles, placed longitudinally, like those of fishes, and only assuming its proper character at a later period. The respiratory organs are at first branchiæ, placed, like those of fishes, in the neck, where there are also found branchial apertures similar to those of the lamprey and the shark; and the heart and great vessels are constructed like those of the tadpole, with reference to a branchial circulation. In their conversion to the purposes of aerial respiration, they undergo a series of changes precisely analogous to those of the tadpole.

Mammalia, during the early periods of their development, are subjected to all the transformations which have been now described, commencing with an organization corresponding to that of the aquatic tribes, exhibiting not only branchiæ, supported on branchial arches, but also branchial apertures in the neck, and thence passing quickly to the conditions of structure adapted to a terrestrial existence. The development of various parts of the system, more especially of the brain, the ear, the mouth, and the extremities, is carried still farther than in birds. Nor is the human embryo exempt from the same metamorphoses, possessing, at one period, branchiæ and branchial apertures similar to those of the cartilaginous fishes,* a heart with a single set of cavities, and a brain consisting of a longitudinal series of tubercles; next losing its branchiæ, and acquiring lungs, while the circulation is yet single, and thus imitating the condition of the reptile; then acquiring a double circulation, but an incomplete diaphragm, like birds; afterwards, appearing like a quadruped, with a caudal prolongation of the sacrum, and an intermaxillary bone; and, lastly, changing its structure to one adapted to the erect position, accompanied by a great expansion of the cerebral hemispheres, which extend backwards so as completely to cover the cerebellum. Thus does the whole fabric arrive, by a gradual process of mutation, at an extent of elaboration and refinement, which has been justly regarded as constituting a climax of organic development, unattainable by any other race of terrestrial beings.†

* These facts are given on the authorities of Rathke, Baer, Huschke, Breschet, &c. Ann. des Sc. Naturelles, xv. 266. See, also, the paper of Dr. A. Thomson, already quoted.

† A popular opinion has long prevailed, even among the well informed, that misshapen or monstrous productions, or *lusus naturæ*, as they were termed, exhibit but the freaks of nature, who was believed, on these occasions, capriciously to abandon her usual course, and to amuse herself in the production of grotesque beings, without any special object. But it is now found that all defective formations of this kind are occasioned by the imper-

It must, I think, be admitted that the analogies, on which the hypothesis in question is founded, are numerous and striking; but great care should be taken not to carry it farther than the just interpretation of the facts themselves may warrant. It should be borne in mind that these facts are few, compared with the entire history of animal development; and that the resemblances which have been so ingeniously traced, are partial only, and fall very short of that universality, which alone constitutes the solid basis of a strictly philosophical theory. Whatever may be the apparent similarity between one animal and another, during different periods of their respective developments, there still exist specific differences, establishing between them an impassable barrier of separation, and effectually preventing any conversion of one species into another, however nearly the two may be mutually allied. The essential characters of each species, amidst occasional varieties, remain ever constant and immutable. Although gradations, to a greater or less extent, may be traced among the races both of plants and animals, yet in no case is the series strictly continuous; each step, however short, being in reality an abrupt transition from one type of conformation to another. In many instances the interval is considerable; as, for example, in the passage from the invertebrate to the vertebrated classes; and, indeed, in every instance where great changes in the nature and arrangement of the functions take place.* It is in vain to allege that the original continuity of the series is indicated by a few species presenting, in some respects, intermediate characters, such as the *Ornythorhyncus*, between

feet development of some parts of the embryo, while the natural process is carried on in the rest of the system; and thus it happens that a resemblance may often be traced, in these malformations, with the type or the permanent condition of some inferior animal. Hence, all these apparent anomalies are, in reality, in perfect harmony with the established laws of organic development, and afford, indeed, striking confirmations of the truth of the theory here explained.

* See a paper on this subject, by Cuvier, in the Ann. des Sciences Naturelles, xx. 241.

birds and mammalia, and the *Cetacea*, between fishes and warm-blooded quadrupeds; for these are but detached links of a broken chain, tending, indeed, to prove the unity of the designs of Nature, but showing also the specific character of each of her creative efforts. The pursuit of remote and often fanciful analogies has, by many of the continental physiologists, been carried to an unwarrantable and extravagant length; for the scope which is given to the imagination in these seductive speculations, by leading us far away from the path of philosophical induction, tends rather to obstruct than to advance the progress of real knowledge. By confining our inquiries to more legitimate objects, we shall avoid the delusion into which one of the disciples of this transcendental school appears to have fallen, when he announces, with exultation, that the simple laws he has discovered have now explained the universe;* nor shall we be disposed to lend a patient ear to the more presumptuous reveries of another system builder, who, by assuming that there exists in organized matter an inherent tendency to perfectibility, fancies that he can supersede the operations of Divine agency.†

Very different was the humble spirit of the great Newton, who, struck with the immensity of nature, compared our knowledge of her operations, into which he had himself penetrated so deeply, to that of a child gathering pebbles on

* "L'univers est expliqué, et nous le voyons; c'est un petit nombre de principes généraux et féconds qui nous en ont donné la clef." Serres, Ann. des Sc. Nat. xi. 50.

† Allusion is here made to the celebrated theory of Lamarck, as exposed in his "Philosophia Zoologique." He conceives that there was originally no distinction of species, but that each race has, in the course of ages, been derived from some other, less perfect than itself, by a spontaneous effort at improvement; and he supposes that infusorial animalcules, spontaneously formed out of organic molecules, gave birth, by successive transformations, to all other animals now existing on the globe. He believes that tribes, originally aquatic, acquired by their own efforts, prompted by their desire to walk, both feet and legs, fitting them for progression on the ground; and that these members, by the long continued operation of the wish to fly, were transformed into wings, adapted to gratify that desire. If this be philosophy, it is such as might have emanated from the college of Laputa.

the sea-shore. Compared, indeed, with the magnitude of the universe, how narrow is the field of our perceptions, and how far distant from any approximation to a knowledge of the essence of matter, of the source of its powers, or even of the ultimate configurations of its parts! How remote from all human cognizance are the intimate properties of those imponderable agents, Light, Heat, and Electricity, which pervade space, and exercise so potent a control over all the bodies in nature! Doubtless, there exist around us, on every side, influences of a still more subtle kind, which "eye hath not seen, nor ear heard," neither can it enter into the heart or imagination of man to conceive. How scanty is our knowledge of the mind; how incomprehensible is its connexion with the body; how mysterious are its secret springs, and inmost workings! What ineffable wonders would burst upon us, were we admitted to the perception of the spiritual world, now encompassed by clouds impervious to mortal vision!

The Great Author of our being, who, while he has been pleased to confer on us the gift of reason, has prescribed certain limits to its powers, permits us to acquire, by its exercise, a knowledge of some of the wondrous works of his creation, to interpret the characters of wisdom and of goodness with which they are impressed, and to join our voice to the general chorus which proclaims "His Might, Majesty, and Dominion." From the same gracious hand we also derive that unquenchable thirst for knowledge, which this fleeting life must ever leave unsatisfied; those endowments of the moral sense, with which the present constitution of the world so ill accords; and that innate desire of perfection which our present frail condition is so inadequate to fulfil. But it is not given to man to penetrate into the counsels, or fathom the designs of Omnipotence; for in directing his views into futurity, the feeble light of his reason is scattered and lost in the vast abyss. Although we plainly discern intention in every part of the creation, the grand object of the whole is placed far above the scope of our comprehension. It is impossible, however, to conceive that this enormous expenditure of power, this vast accumulation of contrivances and of machinery, and this profusion of existence resulting from them, can thus, from age to age, be prodigally lavished, without some ulterior end. Is Man, the favoured creature of nature's bounty, "The paragon of animals," whose spirit holds communion with celestial powers, formed but to perish with the wreck of his bodily frame? Are generations after generations of his race doomed to follow in endless succession, rolling darkly down the stream of time, and leaving no track in its pathless ocean? Are the operations of Almighty power to end with the present scene? May we not discern, in the spiritual constitution of man, the traces of higher powers, to which those he now possesses are but preparatory; some embryo faculties which raise us above this earthly habitation? Have we not in the imagination, a power but little in harmony with the fetters of our bodily organs; and bringing within our view purer conditions of being, exempt from the illusions of our senses and the infirmities of our nature, our elevation to which will eventually prove that all these unsated desires of knowledge, and all these ardent aspirations after moral good, were not implanted in us in vain?

Happily there has been vouchsafed to us, from a higher source, a pure and heavenly light to guide our faltering steps, and animate our fainting spirit, in this dark and dreary search; revealing those truths which it imports us most of all to know, giving to morality higher sanctions; elevating our hopes and our affections to nobler objects than belong to earth, and inspiring more exalted themes of thanksgiving and of praise.

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THE END.