PALEY

PALEY'S NATURAL THEOLOGY;

WITH

ILLUSTRATIVE NOTES,

BY

HENRY, LORD BROUGHAM, F.R.S., AND SIR C. BELL, K.G.H., &c.

AND AN INTRODUCTORY

DISCOURSE OF NATURAL THEOLOGY,

BY LORD BROUGHAM:

TO WHICH ARE ADDED,

SUPPLEMENTARY DISSERTATIONS,

AND A TREATISE ON ANIMAL MECHANICS,

BY SIR CHARLES BELL.

WITH NUMEROUS WOODCUTS.

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ILLUSTRATIONS

OF

PALEY'S NATURAL THEOLOGY.

BY

SIR CHARLES BELL, K.G.H., F.R.S., L. & E.

NATURAL THEOLOGY.

I.

MECHANISM OF THE FRAME.

ARCHDEACON PALEY has, in two introductory chapters of his Natural Theology, given us the advantage of simple, but forcible language, with extreme ingenuity, in illustration. But for his example, we should have felt some hesitation in making so close a comparison between design, as exhibited by the Creator in the animal structure, and the mere mechanism, the operose and imperfect contrivances of human art.

Certainly there may be a comparison; for a superficial and rapid survey of the animal body may convey the notion of an apparatus of levers, pulleys, and ropes, which may be compared with the spring, barrel, and fusee, the wheels and pinions, of a watch. But if we study the texture of animal bodies more curiously, and especially if we compare animals with each other—for example, the simple structure of the lower creatures with the complicated structure of those higher in the scale of existence—we shall see that, in the lowest links of the chain, animals are so simple, that we should almost call them homogeneous; and yet in these we find life, sensibility, and motion. It is in the animals higher in the scale that we discover parts having distinct endowments, and exhibiting complex mechanical relations. The mechanical contrivances which are so obvious in man, for instance, are the provisions for the agency and dominion of an intellectual power over the materials around him.

We mark this early, because there are authors who, looking upon this complexity of mechanism, confound it with the presence of life itself, and think it a necessary adjunct—nay, even that life proceeds from it; whereas the mechanism which we have to examine in the animal body is formed with reference to the necessity of acting upon, or receiving impressions from, things external to the body, a necessary condition of our state of existence in a material world.

Many have expressed their opinion very boldly on the necessary relation between organisation and life, who have never extended their views to the system of nature. To place man, an intelligent and active being, in this world of matter, he must have properties bearing relation to that matter. The existence of matter implies an agency of certain forces; the particles of bodies must suffer attraction and repulsion, and the bodies formed by the balance of these influences upon their atoms or particles must have weight or gravity, and possess mechanical properties. So must the living body, independently of its peculiar endowments, have similar composition and qualities, and have certain relations to the solids, fluids, gases, heat, light, electricity, or galvanism, which are around it. Without these, the intellectual principle could receive no impulse—could have no agency and no relation to the material world. The whole body must gravitate or have weight, without which it could neither stand securely nor exert its powers on the bodies around it. But for this, muscular power itself, and all the appliances which are related to that power, would be useless. When, therefore, it is affirmed that organisation or construction is necessary to life, we may at least pause in giving assent, under the certainty that we see another and a different reason for the construction of the body. Thus we perceive, that as the body must have weight to have power, so must it have mechanical contrivance, or arrangement of its parts. As it must have weight, so must it be sustained by a skeleton; and when we examine the bones, which give the body height and shape, we find each column (for in that sense a bone may be

first taken) adjusted with the finest attention to the perpendicular weight that it has to bear, as well as to the lateral thrusts to which it is subject in the motions of the body.

The bones also are as levers, on the most accurate mechanical principles. And whilst these bones are necessary to give firmness and strength to the frame, it is admirable to observe that one bone never touches another, but a fine elastic material, the cartilage, intervenes betwixt their ends, the effect of which is to give a very considerable degree of elasticity to the whole frame. Without such elasticity a jar would reach the more delicate organs, even in the very recesses of the body, at every violent motion; and, but for this provision, every joint would creak by the attrition of the surfaces of the bones. The bones are surrounded with the flesh or muscles. The muscle is a particular fibrous texture, which alone, of all the materials constituting the frame, possesses the peculiar inherent power or endowment of contracting; it is this power which we are to understand when professional men speak of irritability. The contraction of the muscle bears no proportion to the cause which brings it into operation, more than the touch of the spur upon the horse's side does as a mechanical impetus to the force with which the animal propels both himself and rider. Each muscle of the body—and by common estimate there are hundreds—is isolated; and no property of motion is propagated from one to another; they are distinct instruments of motion. The muscles surround the bones, and are so beautifully classed, that in every familiar motion of the limbs some hundreds of them are adjusted in their exact degree, to effect the simplest change in the position of the body.

Each fibre of a muscle, and a muscle may contain millions of fibres, is so attached to the tendon, that the whole power is concentrated there; and it is the tendons of the muscles which, like ropes, convey the force of the muscles to the bones. The bones are passive levers, the muscles are the active parts of the frame.

With all the seeming intricacy in the running and crossing of these tendons, they are adjusted accurately on mechanical principles. Where it is necessary, they run in sheaths, or they receive new directions by lateral ligamentous attachments, or there are placed under them smooth and lubricated pulleys, over which they run; and where there is much friction, there is a provision equal in effect to the friction-wheel of machinery.

Thus the bones are levers, with their heads most curiously carved and articulated, and joined to the intricate relations of the muscles and tendons, they present on the whole a piece of perfect mechanism.

It is with this texture—the coarsest, roughest portion of the animal frame—that our author is running a parallel when he compares it with the common mechanical contrivances of machinery. Whilst these grosser parts of the animal body exhibit a perfection in mechanical adaptation far greater than the utmost ingenuity of man can exhibit in his machinery, let the reader remember that they bear no comparison with the finer parts of the animal body; such, for example, as the structure of those nerves which convey the mandate of the will to the moving parts, or of the vessels which are conveying the blood in the circulation, and where the laws of hydraulics may be finely illustrated; or of those secreting glands where some will affirm the galvanic influence is in operation with something finer than the apparatus of plates and troughs.

But were we to institute a comparison between the mechanical contrivances of man and these finer mechanisms in the animal frame, we must recollect that there are structures in the body much more admirable, as we shall have abundant opportunities of showing as we proceed in the present volume. The organs of the senses, which are so many inlets for the qualities of surrounding matter to excite corresponding sensations and perceptions, will afford us delightful subjects of contemplation, and proofs more conclusive of design in the human body, not only in regard to the system of that body itself, but as it forms a part of the system of the universe.

II.

ON DESIGN AS EXHIBITED IN THE MECHANICAL STRUCTURE OF ANIMAL BODIES.

In all animal bodies, besides those structures on which their economy and much of their vital functions depend, there is a firm texture necessary. Without this, the vegetable would have no characteristic form; and animals would want the protection necessary for their delicate organs, and could not move upon their extremities. We have to show with what admirable contrivance, in the different classes of organised beings, this firm fabric is reared, sometimes to protect the parts, as a shell, and sometimes to give them form and motion, as in the skeleton.

In vegetables, as in animals, there is a certain firm material necessary to support the parts which are the living active organs of their system, and which are so beautiful and interesting. The ligneous or woody fibre is a minute, elastic, semi-opaque filament, which, closing in and adhering to other filaments of the same kind, forms the grain or solid part of the wood. The best demonstration of the office of the woody fibre is in the leaf. When the leaf of a plant is prepared by maceration and putrefaction, and the soft part washed away, there remains an elegant skeleton of wood, which retains the form of the leaf, and which is perfectly well suited to support its delicate organisation. It is the same substance which, when accumulated and condensed, gives form and strength to the roots and branches of the oak; and these, though fantastic and irregular in their growth, preserve a mechanical principle of strength, as obvious to the ship-builder in the knees of timber, as in the delicate skeleton of the leaf. Lord Bacon speaks of "knee-timber that is good for ships that are to be tossed." The woody fibre, though not directly engaged in the living functions of the tree, is yet essential for extending the branches and leaves to the influence of the atmosphere, and by its elasticity under the pressure of the wind, giving what is equivalent to exercise for the motion of the sap. A tree opposed to winds and to a severe climate is dense in its grain, and the wood is preferred by the workman to that which is the growth of a milder climate.

We cannot miss seeing the analogy of the woody fibre with the bones of animals. Bones are firm, to sustain the animal's weight, and to give it form. They are jointed, and move under the action of muscles; and this exercise promotes the activity of the living parts, and is necessary to health. But let us first observe the structure of some of the lower animals. It will be agreeable to find the hard material, though always appropriate and perfect, becoming more and more mechanical and complex in its construction, from the lithophytes, testacea, crustacea, reptiles, fishes, mammalia, up to man.

The texture of a sponge, its form and elasticity, depend upon a membranous and horny substance, to which both siliceous and calcareous spiculæ are added.

Carbonate of lime is the hardening material of shell, united to a membranous or cartilaginous animal matter. Our author describes the slime of a snail hardening into shell by the influence of the atmosphere; but this is a very imperfect and, indeed, erroneous view of the matter. The shell of the oyster, and even the pearl, consist of concentric layers of membrane and carbonate of lime; and it is their lamellated arrangement which causes the beautiful iridescence in the polished surface of those shells.* In the rough outer surface of an oyster-shell we shall see the marks of the successive layers. We have to understand that that which now forms the centre

* See the discoveries of Sir David Brewster on this subject. Phil. Trans. 1814, p. 397.

and utmost convexity of the shell was, at an earlier stage, sufficient to cover the whole animal. But as the oyster grows it throws out from its surface a new secretion, composed of animal matter and carbonate of lime, which is attached to the shell already formed, and projects farther at its edges. Thus the animal is not only protected by this covering, but, as it grows, the shell is made thicker and stronger by successive layers.

The reader will not be unwilling that we should stop here to show that, rudely composed as this covering of the oyster seems to be, it not only answers the purpose of protecting the animal, but is shaped with as curious a destination to the vital functions of respiration and obtaining food as anything we can survey in the higher animals. We cannot walk the streets without noticing that, in the fish-shops, the oysters are laid with their flat sides uppermost; they would die were it otherwise. The animal breathes and feeds by opening its shell, and thereby receiving a new portion of water into the concavity of its under-shell; and if it did not thus open its shell, the water could neither be propelled through its bronchiæ or respiratory apparatus, nor sifted for its food. It is in this manner that they lie in their native beds; were they on their flat surface, no food could be gathered, as it were, in their cup; and if exposed by the retreating tide, the opening of the shell would allow the water to escape, and leave them dry, thus depriving them of respiration as well as food.*

We perceive, then, that the form of the oyster-shell, rude as it seems, is not a thing of chance. Since the shell is a cast of the body of the animal, the peculiar shape must have been given to the soft parts, in anticipation of that of the shell, an instance of prospective contrivance.

That the general conformation of the shell should have relation to what we may term its function, will be

* In confirmation of these remarks, the geologist, when he sees those shells in beds of diluvium, can determine whether the oysters were overwhelmed in their native beds, or were rolled away and scattered as shells merely.

less surprising when we find a minute mechanical intention in each layer of that shell. We should be inclined to say that the earthy matter of the shell crystallises, were it not that the striated or fibrous appearance differs in the direction of the fibres in each successive stratum—each layer having the striæ composing it parallel to one another, but directed obliquely to those of the layer previously formed, and the whole exhibiting a strong texture arranged upon well-known mechanical principles.

Shell is not alive, as true bone is. If the shell of any of the testacea be broken, the surface of the animal secretes a new shell, not, however, by the concretion of mucus, but by the regular secretion of a substance combined of earthy and gelatinous matter.* Delicate experiments have been made by steeping shells in diluted nitric acid, by which it is shown that the carbonate of lime is the earthy material of shells; and that, when that earth is dissolved in the acid, a gelatinous substance of the form of the shell remains.

Crustaceous animals, such as the lobster and crab,† have their shell formed of the same substances as the testacea, but with the addition of phosphate of lime to the carbonate of lime. A question may arise, How do these animals grow? It is said that they cast their shells and remain retired until a new shell is secreted; and Réaumur has given a very particular account of the process of separation in the cray-fish. Naturalists have not found these cast-off shells. If they be not cast, the animals must, at a particular season, have their shells so softened as to permit sudden expansion of their bodies within; yet it would be difficult to say by what internal means this shell could be thus softened and made pliant. We presume the reason that the shells of the crustacea are not found in our museums is because they are not thrown off at once, but that the portions are detached in succession.

* We owe our knowledge of the formation of shell to the great French naturalist Réaumur, who, by ingenious experiments, showed the distinction of shell and bone, and that the former was secreted from the surface of the animal.

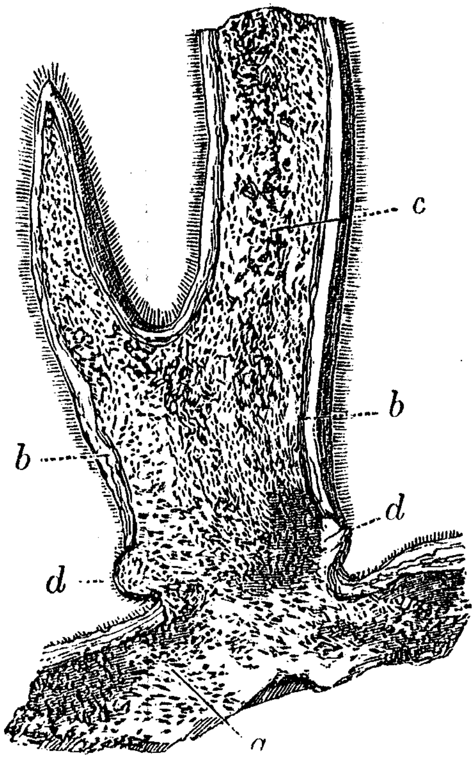
† Vol. ii. p. 224.

In these crustacea we find an approximation to bone, inasmuch as the shell is articulated, and has certain processes directed inwards to which the muscles are attached.

The hardening material of bone is the phosphate of lime, and this earthy substance is not merely united with cartilage or gelatinous matter, but membranes and vessels enter into the composition of bone. Bone is not excreted or thrown out of the system of the animal body, but, on the contrary, it participates in those laws that govern living matter. It is continually undergoing the changes of deposition and absorption, under the influence of blood vessels and absorbing vessels, by which means it grows with the growth of the soft parts.

In fishes, which live in an element that supports the weight, the bones have a very large proportion of elastic cartilage in their composition, and some have so little of the phosphate of lime in their bones, as to be denominated cartilaginous fishes. Indeed, in the higher classes of animals which live upon land, there is in the different bones a finely appropriated union of earth, cartilage, and fibre, to give them the due proportion of resistance, elasticity, and toughness. Not only is the bone of each class of animal peculiar in the proportion of the ingredients, but each bone of the skeleton, as of man, has a due proportion of earth, and cartilage, and fibre, to suit its office. The temporal bone, in which the ear is situated, is as dense as marble (it is called *os petrosum*), and of course is suited to propagate the vibration of sound: the heel-bone, or the projection of the elbow, on which the powerful muscles pull, is, on the other hand, fibrous, as if partaking of the nature of a tendon or rope; whilst the columnar bones, which support the weight, have an intermediate degree of density and an admirable form, as we shall see presently.

Let us consider the structure, growth, and decay of the deer's horns, as an example of the most rapid growth of bone, and a curious instance of its appropriation to a particular purpose. And, first, why should these antlers be deciduous, falling at an appointed season? The breeder of domestic cattle and horses endeavours to propagate the favourite qualities of fleece or carcase, of speed or power, by crossing. Nature accomplishes her purpose by giving to the strongest.



[Section of the Root of a Deer's Horn.]

The antlers of the stag which is in maturity and vigorous health grow with the greatest spread of palms and crotches; with the growth of the horn there is increase of strength in the neck and shoulder.* We cannot be surprised then, that, in contention with his rivals, he that carries the largest antlers should obtain supremacy over the herd. After the season his antlers fall, and we then find the stag feeding with the other males, which before he had driven off. Be this, however, as it may,

* The carotid artery, which nourishes the head, increases rapidly in size during the growth of the antlers.

the growth and fall of the horn is a remarkable phenomenon, and deserving further consideration.

The horn of the deer is bone, and is formed as an internal part, that is to say, it is covered during its growth. It grows from the outer table of the skull, *a;* but there extends, at the same time, from the integuments of the head, a soft vascular covering, *b*, like velvet, so that, during the whole period of its growth, the horn, *c*, has around it a tender soft covering, full of vessels, and which is necessary to its growth and support. But when the horn has acquired its full form and strength, this velvet covering is destroyed by a very curious process. At the root of the horn, near the skull, a circlet of tubercles, *d*, called the burr or pearl, is found; the principal vessels run between these tubercles, and, as the tubercles grow, they close in upon the ascending blood-vessels, compress them, and prevent their conveying blood to the horn; then the membrane, which was vascular, becomes insensible and dead, and in time is rubbed off.

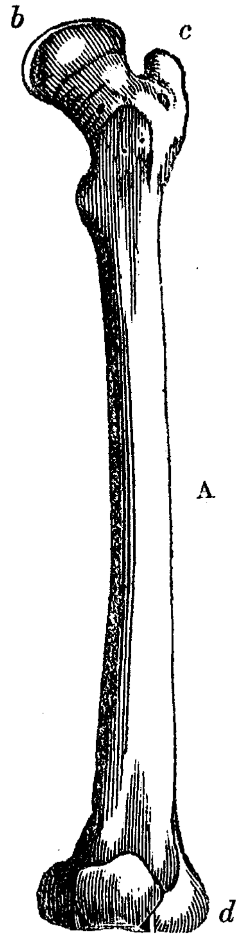
In old treatises on hunting, the separation of the outer cuticle, or velvet, is called fraying; and the huntsman, in leading on his hounds upon a hart of many "tines," judges of his size and strength by the fraying-post—the height of the tree against which he has been butting and rubbing his horns to separate the outer covering. The horns, when the velvet is detached, are now perfect. It is after this that the stag seeks the female in the depth of the forest; and now it is that, in encountering his rivals, fierce contests ensue. They dart against each other with great fury, take no repose, and in a very few weeks become quite exhausted. In the museum of the College of Surgeons there are two superb sets of antlers, entangled and wedged together; they belonged to two males, which had struck so fiercely against each other, that they could not withdraw their horns, and being thus strangely locked together, they starved, and were found dead. The stag is a very different animal, in regard to strength, at different seasons of the year. He feeds, too, on different herbage, sometimes preferring the broom and heath; at another season he resorts to copses, springs, and corn-fields; and these correspond with his different condition as to strength and fatness, and with his passions. It is after the period of contention that the stag is once more found in the copses and underwood, feeding peacefully with his former rivals. And now the process of absorption takes place at the root of the horns, and they are shed: sometimes one is carried a considerable time after the other is fallen; and it is observed that the oldest and strongest harts shed their antlers the soonest. The remarkable circumstance is, that such is the provision, through the absorption at the root of the horn, that a slight shock will now detach that which bore the united force of the two combatants before. The fallow-deer have the same habits and passions; but they will contend in herds for favourite pasture-grounds, and divide into parties under the oldest and strongest of the herd. Who can doubt that the antlers are for a temporary purpose, since, for the greater part of the year, they are either wanting, or in a tender state of growth? Nature bestows them only as arms for the combat which is to decide for the strongest, and give a sire to the herd.

We shall now advert to the forms of the bones of the greater animals, and to those of man. That the bones which form the interior of animal bodies should have the most perfect shape, combining strength and lightness, ought not to surprise us, when we find this in the lowest vegetable production.

A reed, or a quill, or a bone, may be taken to prove that in nature's works strength is given with the least possible expense of materials. The long bones of animals are, for the most part, hollow cylinders, filled up with the lightest substance, marrow; and in birds the object is attained by means (if we may be permitted to say so) still more artificial. Every one must have observed that the breast-bone of a fowl extends along the whole body, and that the body is very large compared with the weight: this is for the purpose of rendering the creature specifically lighter and more buoyant in the air, and that it may have a surface for the attachment of muscles equal to the exertion of raising it on the wing.

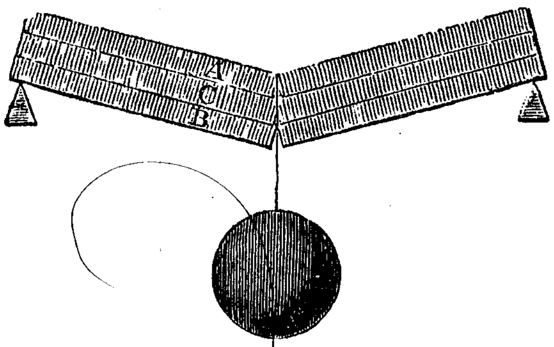
This combination of lightness with increase of volume is gained by air-cells extending through the body, and communicating by tubes between the lungs and cavities of the bones. By these means the bones, although large and strong to withstand the operation of powerful muscles upon them, are much lighter than those of quadrupeds.

The long bones of the human body, being hollow tubes, are called cylindrical, though they are not accurately so, the reason of which we shall presently explain;



[A, section of the femur, or thigh-bone, to show the hollow of its shaft, and the cancellated structure of its upper and lower ends; *b*, the head, by which it is articulated to the pelvis; *c*, the great trochanter; *d*, the surface by which it is articulated to the leg.]

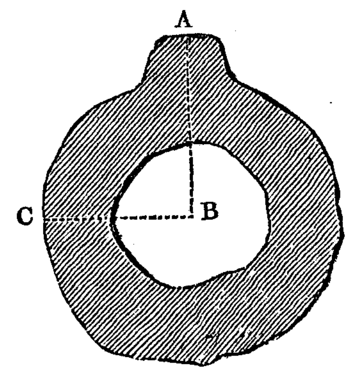
and we shall at the same time show that their irregularities are not accidental, as some have imagined. But let us first demonstrate the advantage which, in the structure of the bones, is derived from the cylindrical form, or a form approaching to that of a cylinder. If a piece of timber supported on two points, thus—



bear a weight upon it, it sustains this weight by different qualities in its different parts. For example, divide it into three equal parts (A, B, C): the upper part A supports the weight by its solidity and resistance to compression; the lowest part B, on the other hand, resists by its toughness or adhesive quality. Between the portions acting in so different a manner, there is an intermediate neutral or central part C, that may be taken away without materially weakening the beam, which shows that a hollow cylinder is the form of strength. We may observe a further illustration of this when a tree is blown down and broken at the stem: to the windward the broken part gapes; it has been torn asunder like the snapping of a rope: to the leeward side of the tree the fibres of the stem are crushed into one another and splintered; whilst the central part is bent. This, we presume, must always be the case, more or less. We may observe, too, why the arch is the form of strength. If this transverse piece of timber were in the form of an arch, and supported at the extremities, then its whole thickness, its centre, as well as the upper and lower parts, would support weight by resisting compression.

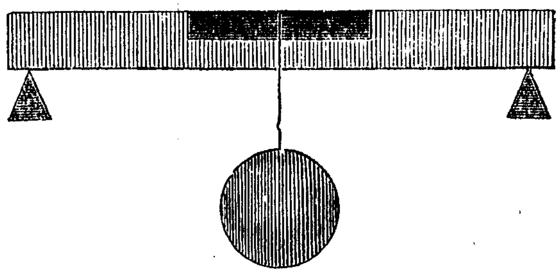
But the demonstration may be carried much farther, to show the form of strength in the bone. If the part of the cylinder which bears the pressure be made more dense, the power of resistance will be much increased; whereas, if a ligamentous covering be added on the other side, it will strengthen the part which resists extension; and we observe a provision of this kind in the tough ligaments which run along the vertebræ of the back.

When we see the bone cut across, we are forced to acknowledge that it is formed on the principle of the cylinder—that is, that the material is removed from the centre, and accumulated on the circumference, thus—



We find a spine or ridge, A, running along the bone, B C, which, when divided by the saw in a transverse direction, exhibits the irregularity, whereof A is the section.

The section of this spine shows a surface as dense as ivory: that part is, therefore, much more capable of resisting compression than the other part of the cylinder, which is common bone. This declares what the spine is, and the anatomists must be wrong who imagine that the bone is moulded by the action of the muscle, or that the spine is a mere ridge, arising by accident among the muscles. It is, on the contrary, a strengthening of the bone in the direction on which the weight bears. If we resume the experiment with the piece of timber, we shall learn why the spine is harder than the rest of the bone. If a portion of the upper part of the timber be cut away, and a harder wood inserted in its place, the insertion of the harder portion of wood increases this property of resistance. With this fact before us we



may return to the examination of the spine of bone. We see that it is calculated to resist pressure, first, because it is farther removed from the centre of the cylinder, and, secondly, because it is more dense, to resist compression, than the other parts of the circumference of the bone.*

This explanation of the use of a spine upon a bone gives a new interest to osteology. The anatomist ought to deduce from the form of the spine the motions of the limb, the forces bearing upon the bone, and the nature and the common place of fracture; while, to the general inquirer, an agreeable process of reasoning is introduced in that department, which is altogether without interest when the "*irregularities*" of the bone are spoken of, as if they were the accidental consequences of the pressure of the flesh upon it.

Although treating of the purely mechanical principle, it is perhaps not far removed from our proper object to remark that a person of feeble texture and indolent habits has the bone smooth, thin, and light; but that nature, solicitous for our safety, in a manner which we could not anticipate, combines with the powerful mus-

* As the line A B extends farther from the centre than B C, on the principle of a lever, the resistance to transverse fracture will be greater in the direction A B than B C.

cular frame a dense and perfect texture of bone, where every spine and tubercle is completely developed. And thus the inert and mechanical provisions of the bone always bear relation to the living muscular power of the limb, and exercise is as necessary to the perfect constitution and form of a bone as it is to the increase of the muscular power. Jockeys speak correctly enough when they use the term "*blood and bone*," as distinguishing the breed or genealogy of horses; for blood is an allowable term for the race, and bone is so far significant, that the bone of a running horse is remarkably compact compared with the bone of a draught horse. The reader can easily understand, that in the gallop the horse must come on his fore legs with a shock proportioned to the span; and that in the horse, as in man, the greater the muscular power the denser and stronger is the bone. The bone not being as a mere pillar, intended to bear a perpendicular weight, we ought not to expect uniformity in its shape. Each bone, according to its place, bears up against the varying forces that are applied to it. Consider two men wrestling together, and then think how various the direction of the resistances must be: now they are pulling, and the bones are like ropes; or again, they are writhing and twisting, and the bones bear a force like the axle-tree between two wheels; or they are like a pillar under a great weight; or those bones are acting as levers. We see, therefore, why, to withstand these different shocks, a bone should consist, as we have stated, of three parts, the *earth* of bone (subphosphate of lime) to give it firmness; *fibres* to give it toughness; and *cartilage* to give it elasticity.

We may pursue this subject a little farther still, taking the text of our author—"*The proportioning of one thing to another.*" Chap. xvii. sec. v.

The great functions by which animals live and breathe and are nourished are the same through the whole chain, from the simplest polypus or mass of jelly that floats in the sea, to the largest and most complex of all terrestrial creatures. The appetite for food, the powers of assimilation, circulation, aëration, secretion, are the same functions in all living creatures, only modified by their size or condition. When we consider the astonishing variety in the shapes of animated beings, we are apt to forget the necessity of apportioning their size and strength, not only to the vegetable productions and to the materials found on the surface of the earth, but to the magnitude of the globe—to the "great motions that are passing in the heavens." On that plan of living structure which pervades all the varieties of animals in which bones afford resistance and muscles activity, there must be a limit to stature. The resisting parts of the smaller animals, which have an external covering instead of bones, have comparatively much less material in them than the larger. Accordingly, philosophers have contrasted the power of the flea with that of the horse, deciding greatly in favour of the former. The rationale of this is not quite apparent at first; but a little consideration will convince us, that the resisting material being exterior to the animal's body, and consequently removed from the centre, it must possess more power against transverse fracture, as well as bestow a mechanical advantage for the action of the muscles. But this is not all: any degree of density and strength may be given to it, from its being a mere secretion, and being unorganized. We may compare, however, the bones of man with those of the elephant, or other huge animals.* Now it would seem that the material of bone (which we must recollect is porous, since it constitutes a living part, and is nourished by blood-vessels) could not, by any variety of conformation, bear up a greater mass than that of the elephant. On examining the bones of these immense animals, including the megatherium and rhinoceros, they are dense and strong, and clumsy, as we would term it; their spines and processes are large, and their cavities filled up: all which indicates, that to support a larger animal on extremities, some other material than the vascular bone would be required. Those immense bones that are found in digging the earth, and which, in ignorant ages, have given rise to strange fancies, are the bones of animals inhabiting the water—whales or reptiles, whose bulk was extended in the water, or that crawled on their bellies, and they could never have given support sufficient to have raised their enormous weight on extremities. With regard to the position, that "a chicken roosting on its perch is related to the spheres revolving in the firmament," I have elsewhere illustrated the necessity of a fixed point from which the muscles can act, and that the necessity of resistance implies that of weight, and that that weight must be proportioned to the mass of the globe we inhabit, as well as to the power of the muscular frame.*

* Vol. iii. p. 7.

* See the introduction to the Bridgewater Treatise on "The Hand."

III.

DESIGN OR MECHANICAL CONTRIVANCE AS EXHIBITED IN THE BONES OF THE HEAD AND THEIR JOININGS.

WE have elsewhere spoken of the "architecture" of the skull, which, though at first a startling term, has been acquiesced in from the remarkable instances that we have given of design, in comparing the texture and connexion of the bones with the art of the builder and carpenter. The more important the part is to life—the more vital the organ, we find the texture or fabric which protects it the more perfect. The human skull presents us with many curious proofs that the forces or injuries to which it is exposed are calculated and provided against. But we shall take our first examples from the skulls of animals; and here we see that the brain is not covered in the same manner in all, but that in each variety there is a provision against the forces to which the skull is subjected. The skull of a dog is hardly in any respect like the skull of a ram; the bones of the former are thin; the line of union, which is called the *suture*, is simple; it is not provided to withstand percussion: but in the latter animal there is reared over the proper brain-case a series of arched cells of strong bone, and each bone is joined to another by a line, serrated, deep, and regular; the mechanical strength of the union always corresponding with the strength of the bones; and the whole being formed into a base suited for the support of the horns, and calculated to sustain the shock when the animal butts with the whole weight and strength.

We might contrast the skull of the ram or goat with that of the tiger, where the strength is in its jaws. This animal, too, has the brain-case small, and, as it

[The engraving represents the irregular line of union of the bones of the skull as seen on the outer surface.]

were, buried in the head; but the jaws, instead of being spongy bones, as in man, are dense and strong to sustain the teeth; for what would avail these teeth, long and sharp and strong, could they be twisted from their socket? and what would avail the strength of the jaws, and length and depth of the teeth, were not the proper skull surrounded with spines and arches of bone dense and strong enough to give attachment to the muscles of the jaws? Thus, in the carnivorous animal, the strength of the bony textures of the head is all concentrated in the jaws of the animal, and corresponds with its instinct to hold and rend its prey.

But when the lion or the tiger have struck down their prey—and have gorged themselves and sought their dens, and when the lesser carnivorous animals have cleared the bones—there remains a rich repast which they cannot reach; then comes the hyæna, which cracks the bones, and feeds upon the marrow.

Of all the skulls that can be collected in a museum, the jaws and teeth of the hyæna exhibit the most extraordinary strength: the bones having a clumsy form and dense texture quite peculiar, and suited for the socketing of the strong conical teeth.

We see, therefore, that the fabric of the head, taken as a whole, bears a certain resemblance in all classes of animals; but, though built upon the same general plan, the supports are given to fortify the points which bear the shock.

By such more obvious instances of adaptation we are led to inquire whether any similar adjustment of the resisting property of the bone is to be found in the human head. We must carry this along with us in our inquiry, that a shock or vibration going through the great mass of the human brain proves more immediately destructive of the faculties, than the wound which penetrates the substance without a concussion. When we contemplate the condition of a child, its fearlessness, its restless activity, the falls and knocks it gets, we must perceive that were not the textures of the bones and the brain adjusted, the child when it fell must have lain insensible, instead of rising and crying more from terror than the sense of injury.

We may contrast this condition of the child with that of an old man losing his balance and falling on his head, who lies insensible from the shock. Is it not apparent that there is here a calculation of the accidents of life, and a provision against them, which yet leaves us threatened with danger, and, therefore, on our guard?

The difference in the textures of youth and age are instructive as to the causes of the diversity. The brain of the old man is firm; the vibration injures its fibre. The brain of the child is soft, and in infancy it may be moulded to any shape. Then, again, the texture of the bone is entirely different, and hardly like the same substance. It is thin and pliant in the child, actually dimpled by a blow; whilst in age it is brittle from its density, and the vibration of the blow runs round it; or if it be broken, it is like a piece of sharp glass entering the tender parts beneath.

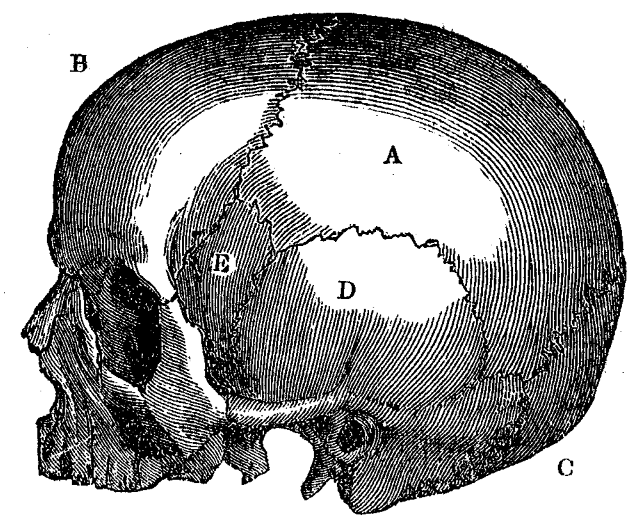
Much more than will stand inquiry has been said of the forms of the head, in reference to the contained organs; but there is a simple demonstration which should precede all this: the forms of the skull bear a relation to pressure and injury from without, and the parts most exposed are most protected. A man falling backwards has the back of his head exposed to injury; and the examination and section of the bone at this part shows how nature has strengthened it, by giving it greater thickness and prominence, and by groining it within. We say

groining it; for there is nothing more resembling the strong groinings or arches of the ground-story of a great building, than the ridges of the skull at this part of its base, which cross at a centre corresponding with the prominence of the occiput.

In front, the form of the skull exhibits a provision not less distinct in its object. The parts of the forehead which are most prominent and exposed (*eminentiæ frontales*) exhibit, on their section, a thicker and denser bone; whilst the lower part of the forehead is formed of cells or sinuses, which, throwing off the outer wall of the skull from the surface of the brain, still more effectually protects it.

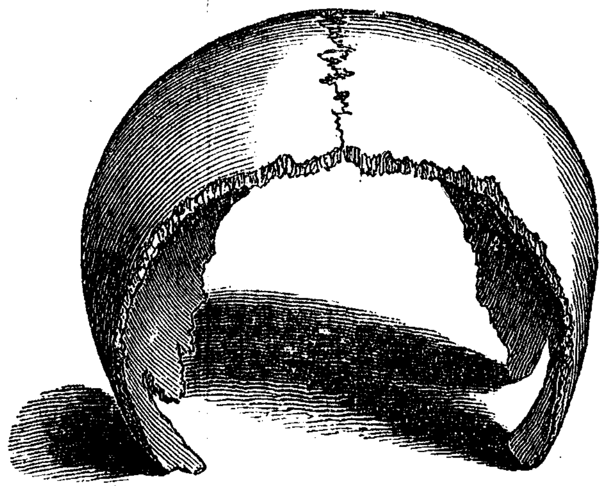
A person tumbling sideways pitches on the shoulder, and the convexity of the head comes to the ground precisely on that point (the centre of the parietal bone) where the bone is thickest and most dense.

It is, on the whole, impossible to study the forms of the head without acknowledging that the shape, thick-



A. The *parietal* bone. C. The *occipital* bone.
B. The *frontal* bone. D. The *temporal* bone.
E. The *sphenoid* bone.

ness, and texture of the skull have reference to the liability to pressure and blows from without.



[The figure represents the two parietal bones—forming an arch, or a surmounted dome.]

To take a further example:—It seems very natural, in carrying a burden, to poise it on the head. Now, whether we take the carpentry (called a *centering*) on which the stones of the arch of a bridge are laid in building it, or the arch of stone, or a dome—(for with all these the bones of the head may be aptly compared)—there has been nothing ever contrived so perfect as the joining of the bones of the head to resist both pressure above, and straining at the sides. And if, on this subject, we solicit the reader's attention more particularly to these joinings, it is because, in books merely anatomical, they are apt to be treated like things of accident, and described as the running of the fibres of one bone into another, the necessary consequence of their mode of growth; or the accidental effect of the pressure of the muscle: whereas, on the contrary, the finest tools of the carpenter could make nothing so perfect or so demonstrative of design.*

These provisions would surely have met with earlier attention had men contemplated in a true view the object of the animal frame-work; which is not to give absolute safety against inordinate violence, but to balance the chances of life,—leaving us still under the conviction, that pain and injury follow violence: so that our experience of the injury, and our fear of pain, whilst they are the principal protection to life, lay the foundation of important moral qualities in our nature.

* This subject is pursued in more detail in the treatise given as Appendix II. originally published by the Society for the Diffusion of Useful Knowledge, under the title of "Animal Mechanics." It is there shown that the bony substance of the skull separates, in the maturity of man, into two plates or tables, and of different degrees of hardness, with an intermediate soft substance; and that by this arrangement of substances of different densities, a shell or covering is given for the protection of the brain, opposing sufficient resistance to pressure, and at the same time calculated to stifle vibration from a blow.

IV.

OF THE JOINTS.

In comparing the skeleton with carpentry, or anything artificial that admits of comparison with it, we remark that, in the bones, there is not a straight line, or regular form, whether they serve as a shaft, axle, or lever; while, in the other, every part is levelled and squared, or formed according to some geometrical curve. This would lead a superficial thinker to conclude that the bones were formed irregularly, or without reference to principle; but the consideration of by Whom formed, leads to a review; and a deeper examination brings with it the conviction that the curves, spines, and protuberances of the bones are formed with a relation to the weight which they bear, and the thrusts and twists to which they are subjected in the different motions of the body.

If we observe the various postures of a man at any manual labour, or under a weight, or running, or leaping, or wrestling, we shall be convinced that no carpentry of the bones, formed upon geometrical lines or curves, could suit all this variety of motion. No splicing, dovetailing, cogging, or any of all the various shapes into which the carpenter or joiner cuts his material, could enable them to withstand the motions of the body, where it is so utterly impossible to estimate the forces, or to calculate upon the variety in the motion.

That the varieties in the forms of the bones are not irregular, nor accidental, but are related to the motions to be performed, is apparent in the close examination of the human skeleton, and still more clearly evinced by comparative anatomy.

The shapes of the bones are very closely related to the motions to be performed by the different joints. Let us observe the enlargement of the diameter of the bone at an articulation. This expansion of the articulated surface of the bone gives power to the binding ligaments, by removing them from the centre of motion; and by the increase of surface and additional strength of ligament, the danger of dislocation is much diminished. The friction of two bodies whose surfaces move upon one another is not increased by the extent of surface, the pressure remaining the same. Hence the enlargement of the surfaces of the joint is attended with greater security without there being additional friction. But, for the most part, the surfaces of the bones, instead of sliding upon one another, have a rounded form, and roll upon each other. Now the friction, in this case, depends upon the diameter of the body which rolls, and is small in proportion as the diameter of that body is great, the weight being the same. By this we see that the large bones forming the knee-joint, for example, have every advantage of greater strength without increased friction.

Our author has perhaps dwelt sufficiently on the smoothness given to the articulating surfaces of the bones by the cartilages and the synovial or lubricating fluid, vulgarly called joint-oil (and ignorantly so called); and after these general observations, in order fully to comprehend the fine adjustment of each bone in its articulation, we should require to go minutely into the anatomy. Then we should find with how curious a mechanical adaptation the motions are permitted in the prescribed direction and checked in every other. We should be called to observe, also, how the motions of one joint are related to those of another; and how, by the combination of joints, each of which is securely checked and strengthened, there is a facility and extent of motion produced by their combination: for example, in the arm and hand, where the motions are free, and varied in every possible direction.

It is interesting to see how the joints of the lower extremities are modified in man in comparison with those of the upper. We have elsewhere remarked that the bones of the human pelvis, thigh, and leg exceed those of all other animals in relative size, which shows a provision for the erect position of man. The same is evinced in the form of the joints, as the ankle, knee, and hip; for whilst their combinations give every necessary degree of motion consistent with security, there is a happy provision, producing at once firmness and mobility. That is to say, when the limb is thrown forward in walking or running, it is loose, and capable of being freely directed; so that we plant it with every convenience to the irregularity of ground: but when the body is carried forward to be perpendicular over that limb, it acquires, by the curious adjustment of the bones, a firmness equal to that of a post. Again, when the body is still further thrown forward, and the limb is disencumbered of the weight of the body, the joints are let loose so as to be bent easily, and to obey the action of the muscles.

V.

OF THE SPINE.

THE spine is the most perfect structure in the whole animal machine. Perhaps, if our words were critically taken, it would be better to say, that the intention of the curious mechanical structure here was the most apparent, and on that account most the object of our admiration. By the skeleton is meant the collection of bones which gives form and strength to the superior class of animals; and as these bones are bound together by a chain of vertebræ, the whole class of these animals is called *vertebrata*, from this most essential part of the skeleton. Besides thus binding the bones together, and forming, as it were, the very centre of the whole, the spine is a tube for protecting the most vital organ of all, the spinal marrow. But, again, when we look upon the skeleton of man as giving him the power of standing erect, we observe that the spine, whilst it retains its other offices, has a new one imposed upon it: it is a pillar for sustaining not only the superior parts of the body, but the globe of the head, which we shall find it protects in a very unexpected manner. The reason of our admiration, then, is in being able to perceive the modes by which these different offices are performed by the construction of this column: how nature has established the most opposite and inconsistent functions in one set of bones;—for these bones are so strong as not to suffer under the longest fatigue or the greatest weight which the limbs can bear; and so flexible, as to perform the chief turnings and bendings of the body; and yet so steady withal, as to contain and defend the most material and the most delicate part of the nervous system.

In some animals, the lowest of the vertebrata, the protecting texture of the spinal marrow hardly deserves the name of vertebral column. In certain fishes,* for example, the spine consists of a cartilage made tough by ligamentous intertexture. In the myxine, this cartilage does not entirely enclose the spinal marrow; for it lies in a deep groove on the upper part of the spine. But let us not suppose that in fishes there is any imperfection in the vertebral column: it is an elastic column, on which the muscles act so as to become the means of powerful locomotion; and in all fishes the spine has, more or less, this remarkable elasticity. Ascending in the scale of animals, we find the cartilage forming the spinal column subdivided by cavities which contain a gelatinous fluid; and these cavities being surrounded with a strong but elastic ligamentous covering, nothing can be conceived more admirably adapted to give a springiness to the whole column. Still ascending, we discover that the bony matter becomes deposited between these cavities; and here the separate vertebræ first appear. If two vertebræ of the great shark be taken out together, and the sac between them punctured, such is the elasticity of the walls of this sac, that the fluid will be spouted out to a distance. In other fishes, as the cod-fish (an osseous fish), the structure approaches to that of the mammalia; the intervertebral substance is gelatinous. In the whales, circular concentric ligaments join the vertebræ, and a small portion in the centre consists of a glairy matter. In mammalia, and in man, there are strong and distinct bones of the vertebræ; and these are joined by a ligamentous cartilage, the outer circle of which is remarkably strong, and the central soft and elastic. The toughness and strength of the exterior circle, and the soft condition of the centre, make a joint equivalent in action to what might be produced by a ball intervening between the surfaces: a facility of motion is thus bestowed which no form of solid could give; and yet the joint is so strong, that the bone breaks from

* Myxine, lamprey, sturgeon, &c.

violence, but the ligamentous cartilage never gives way. When the veterinary surgeon casts a horse, if he be not careful to restrain him, he will twist himself with a force which will break the vertebræ. It is a frequent accident in man; but the texture that gives mobility to the spine never yields.

The next thing admirable in the spine is the manner in which the head is sustained on a column possessing elasticity, and in which the brain is thereby saved from undue concussion in the movements of the body. This object is not attained altogether through the elastic substance in the spine which we have described; but it is owing, in a great measure, to the general form of the spine in man. Had the vertebræ been built up, like a lofty column, of portions put correctly and vertically over one another, the spine would not have had the advantages which result from the structure that we have to describe. As the incumbent weight would then have fallen on the centres of all the bodies of the vertebræ, they must have yielded in a slight degree only. Accordingly, the figure of the italic *ſ* is given to the column, which waving line we need not admire because it is the line of beauty, as some have defined it, but because it is the form of elasticity. The spine being already in a curved shape, it bends easily; the pressure is directed upon the margins of the vertebræ and of the intervertebral substances, and they therefore yield readily; and by yielding, they produce an increase of the curve, a consequent shortening of the whole column, and admit an easy return to their original places. Suppose we rest the palm of the hand upon a walking-cane, which is elastic, but perfectly straight; it bears a considerable pressure without yielding, and when it does yield, it is with a jerk; but if it be previously bent, however we may increase or diminish the pressure, there will be no shock: the hand will be supported, or the cane yield, with an easy and uninterrupted resiliency. Such we conceive to be the end obtained through the double curvature of the spine: that the brain shall receive no shock in the sudden motions of the body.

Were we to give our attention to the processes of bone which stand out from the bodies of the vertebræ, we should find unexpected provisions there also. It is a common remark of anatomists, that the bones of the spine are secured in their proper places by the relations of the surfaces in contact; the surface of the body being oblique in one direction, and those of the articulating processes in another—the one therefore preventing the bone being dislocated forwards, and the others preventing it being displaced backwards. There is something more than this. The articulating processes consist of two broad surfaces, which are inclined in such a manner that they slide upon one another—that is to say, the articulating surface of the vertebra above, being itself inclined, rests upon another which is also inclined. As the intervertebral substances of the bodies yield and recoil, the articulating process of the upper vertebra shifts upon the inclined surface of the process on which it is seated, ascending and descending; but the impediment is greater the more the vertebra descends, thus adding to the elasticity and security of the whole, and preventing the abrupt shocks which would be the consequence of the surfaces being horizontal. If a cannon were made to recoil upon an ascending plane, or a surface forming a portion of a circle, it would represent the mechanism of the articulating processes of the vertebræ.

Let the separate spine be presented before us, it stands up, like a mast, broad and strong below, and tapering upwards. The mast of a ship is supported by the shrouds and stays; and if we sought for an analogy with these, we must fix upon the long muscles of the back, which run along the spine to sustain it. But as a mast goes by the board in a storm, we see where the spine would have been most in danger, had not nature provided against it. When we start forward in walking or running it is by the exertion of the muscles of the lower extremities, and the body follows. Did the spine stand directly up perpendicularly, it would sustain a shock or jar at its base in these sudden motions. We see, therefore, the intention of the lower vertebræ being inclined forwards from their foundation on the sacrum: for by this

means, the jar which might endanger the junction of the lowest piece, is divided amongst the five pieces that form the curve. The same thing is seen in the quadruped: for as the spine in the back and loins lies horizontally, and the neck rises towards the perpendicular, there would be danger of dislocation, if the vertebræ of the neck rose suddenly and abruptly from the body: there is, therefore, at the lowest part of the neck a sweep or semicircle formed by the junction of several vertebræ, to permit the head to be erected; a remarkable example of which is shown in the stag.

We have elsewhere observed, that when a delicate piece of mechanism is contrived by the hands of man, it may be locked up and preserved. But the most delicate textures of the living frame stand distinguished, above all, by this quality, that if they be not put to use, they very quickly degenerate. Not only is the faculty of action lost by inaction, as every one must be aware takes place in the functions of his own mind, and in the exercise of his senses, but the texture of the organs quickly degenerates. If by accident a limb should lose certain movements, the muscles, nerves, vessels, which nature intended to be subservient to these motions, become in a few weeks or months so wasted that they are hardly recognizable by the anatomist. If we apply this acknowledged principle to the spine, and take along with us that the texture of bone, cartilage, ligament, tendon, muscle, all the parts which enter into its structure and are necessary to its perfection, however varying in solidity or composition, retain their perfection by being exercised, we shall readily perceive the effect of confinement on young females. Without any positive disease, but from being over-educated in modes which require sedentary application, the spine becomes weak and loose in texture, and yields to the prevailing posture, whatever that may be. We mention this because it is a principle important in every consideration to each individual, and applicable to both body and mind.

The French philosophers have entertained the notion that the central parts of all animals are more permanent in their construction, whilst the extremities are subject to variety—a theory partly admitted by some eminent physiologists among ourselves, and which introduces obscurity and hypotheses into one of the most remarkable proofs of design. Dr. Roget, in his excellent 'Bridgewater Treatise,' has taken up this idea.

A spinal marrow belongs to the whole of the vertebrated class of animals; and the spinal marrow must be protected by bone: accordingly, as the principal use of the spine is permanent, so must its form be. Yet whenever there is a change in the action, or rather in the play of the spine, we find the vertebræ conformable. Thus the motion of a fish through the water results from a lateral movement of the tail and spine; but were the constituent bones formed like those of other animals of the same class, the lateral or transverse processes of the verterbræ would interfere with this motion: they are therefore removed, and in order to give strength to the chain of bones, the spinous processes are prolonged towards the back, and corresponding processes project towards the viscera. In the cetacea, as the whale and dolphin, &c., the position of the tail is reversed; it lies out horizontally; and the vertebræ correspond. These animals must rise to breathe the air, and their tails are thus provided to raise them easily to the surface; a proof, if any were wanted, that the spine, the very centre of the system, is accommodated to the main function of respiration.

The tail of animals is the prolongation of the spine. But it seems extraordinary that any one should make this the ground of an hypothesis, that when parts are repeated, they become more and more imperfect as they recede from the centre. It is however referred to in view, because the bones constituting the tail become smaller and rounder, and terminate in cartilage in which there is no bone. Is it not, on the contrary, obvious that the tail of animals is constituted for its proper purpose, firm towards the root, with muscles to play it in all directions, and less firm and more elastic towards the end to carry the brush? Can anything be better adapted to such purposes? Would it be more perfect if there were vertebræ instead

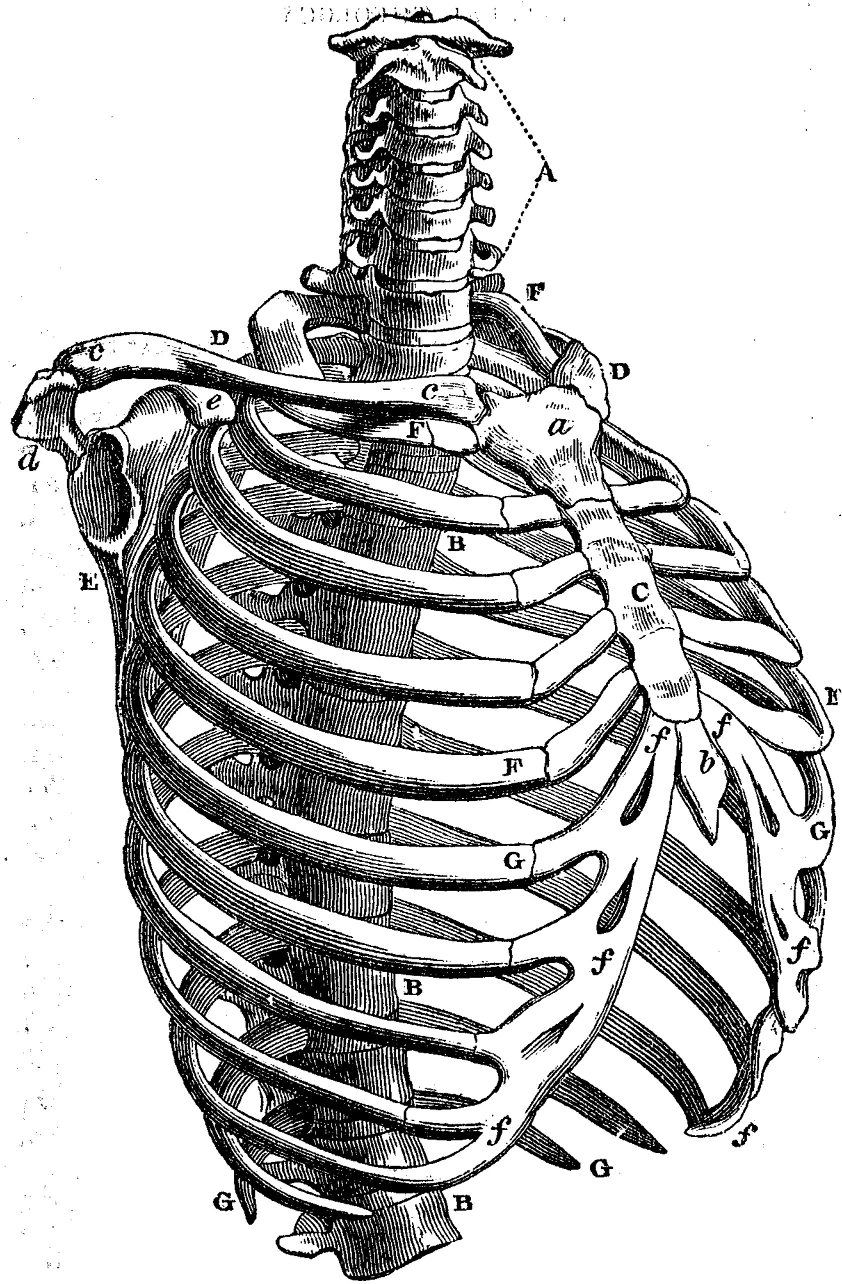
of round bones joined together? In short, corresponding as this part does with its uses, sometimes as a brush to curl round the animal and be a mantle for warmth, sometimes as a rudder in running, sometimes as a fan, and always reaching where the ear or the tongue cannot reach —must all the obvious provisions be lost sight of in the consideration that animal bodies are constituted so imperfectly, that if a part like a vertebra be formed in the centre, repeated or prolonged, each link, as it recedes from the centre, must become less and less perfect, degenerating from what is presumed gratuitously to be its original form?

VI.

OF THE THORAX AND MECHANISM OF RESPIRATION.

Our author might have made more use of the thorax as affording proofs of his great argument. We have here represented the spine, breast-bone, and ribs, as the anatomist articulates them. Were he to make a skeleton in this fashion, it would be fragile in an extraordinary degree, compared with the natural body; and if the skeleton fell, it would inevitably be broken. Let us see, then, what gives protection to the bones in the natural body. The celebrated John Hunter was much engaged in showing by what means elasticity came in aid of the muscular power, both in the textures circulating the blood, and in those ministering to the play of the lungs. We may observe how the same principle conduces to the protection of the ribs as well as assists their motion in respiration.

The anterior part of the rib (*f*) which ekes out the rib (F G) and joins it to the breast-bone (C), is formed of elastic cartilage; and the rib having a free articulation behind to the spine, it results that each rib is possessed of elasticity. The anatomist making no proper substitute for this in the artificial skeleton, the bone breaks easily, like a piece of china. We have another proof in the natural body of the necessity for elasticity. We before observed that a child, rash and unsteady, is liable to a thousand accidents to which those of maturer years are not exposed. Now, during all the active years of life, the whole textures of the frame, and especially of the thorax, both bone and cartilage, possess elasticity, corresponding with the hazards to which youth is subject: in short, the child falls and suffers no injury; when an old man,



[This drawing has been taken from an artificial skeleton, which is seldom articulated correctly. The ribs do not lie here in a natural position; or, if ever they were placed so in the living body, it could only be in violent inspiration, when they are raised to the very utmost. This figure is referred to at p. 91 of Vol. II., but the number of the Appendix is called VII. instead of VI.]

striking his ribs upon the corner of the table, has them fractured. But let us observe the effect of elasticity in the act of respiration.

The ribs do not move to accommodate themselves to the motions of the lungs, but by moving draw the lungs after them, and cause their expansion. The interstices of the ribs being filled up, and a septum closing the thorax below, the enlargement of the cavity permits the lungs to be expanded by the weight of the atmosphere, the air entering them through the windpipe. We at once see the importance of the motions of the ribs, for the expansion of the chest and the play of the lungs. Our author has, however, omitted an essential part of this interesting subject. He has shown that the oblique position of the ribs is necessary to inspiration, and that, by the rising of the anterior part of the rib, the breast-bone is thrust forwards and the cavity enlarged. But the rib has a double motion. It has a motion on its own axis. Suppose a line drawn through the two extremities of a rib, which would represent the string of a bow, that string is stationary, while the bow, representing the rib, revolves; thus the rib, by having its anterior extremity depressed and revolving as it is raised, enlarges the transverse diameter of the thorax as well as the anterior diameter. In this action the cartilage in front is twisted; and the torsion of this elastic matter affects the muscular action in the manner following.

We have understood the act of respiration to be essential to life, and that the expansion of the chest dilates the lungs, gives freedom of circulation through them, and decarbonizes the blood. It is interesting, therefore, to see how a property of dead matter, elasticity, becomes a guard upon life. Every one must feel that it is easier to expire the air than to inspire it; and if we can imagine a person fainting, or in any mode in danger of death (the very word expiring, in its common sense, implies that the last act of life is the expulsion of the breath), if the elasticity tends to enlarge the chest, it must tend to the preservation of life, by restoring the circulation through the lungs. This is exactly what happens from the elastic structure of the whole compages of the chest. The elastic property preserves the chest in a middle state. The muscles of inspiration act against the elasticity: the muscles of expiration also act against it: the elasticity tends, therefore, to maintain an intermediate state of dilatation of the thorax; and accordingly the lungs are preserved in a condition to perform their functions for a certain period at least, after the vital actions would have ceased through the muscles, had there been no such structure.

The great physiologist whom we have already mentioned, John Hunter, taught that when one part performed two functions, there was necessarily an imperfection. We have now the most suitable opportunity of controverting that position: for this texture of the thorax is subservient to many different functions. There is no imperfection evinced in the organ of smelling, because in order to draw in the odoriferous effluvia and make them pass over the olfactory nerve, we use the lungs. Nor do we experience any material interference with respiration, because we enjoy the power of speech through an impulse given to the air in expiration. Further, let us attend to the form and expansion of the chest as conducive to the motion and strength of the arm and hand. The motions of the superior extremity result from muscles which lie upon the chest; and were it not for the expansion of the chest, from the contained atmospheric air, these muscles would not act with sufficient power, or a substitute must have been found either of projecting bones, or of some solid texture, to afford lodgment and attachment to these muscles.

Then, again, considering man in his natural condition, the chances of life would run against him if he were incapable of floating upon water, or if the atmospheric air in his body were not anterior to his centre of gravity. The force of this argument will be understood when we remember that the air contained within the lungs, after a man has made an inspiration, amounts to three hundred and thirty cubic inches.

Looking to the means of guarding life, nothing can be more important than the condition of the lungs, in respect to the atmospheric air within them. The sensibility, and the rapid contraction of the glottis, which is at the mouth of the respiratory tube, is for the purpose of arresting any foreign matter afloat in the atmosphere, which might be drawn in by the stream of inspired air, and so reach the recesses of the lungs. But were this all, the office would be but half performed. The foreign body would be arrested; but how would it be expelled if it lodged? In common expiration the air is never expelled altogether from the lungs: there is enough retained to be propelled against this foreign body, and to eject it. And, but for this, the sensibility of the glottis, and the actions of the expiratory muscles, would be in vain; we should be suffocated by the slightest husk of seed, or subject to deep inflammation by the collection of foreign matter drawn into the air-tubes.

We may here observe, that the instinctive actions for the protection of the body are calculated, if we may say so, for the natural condition of man. The manufacturer is sometimes removed from that condition; and our invention must be taxed, not only to maintain the purity of the atmosphere in which he works, in a chemical sense, but to arrest, or convey away, the small portions of material which may be thrown off by the operations of the flax-dresser, for example, in heckling, or of the cutler, whose occupation it is to grind the steel after the instrument is forged, or of the stone-cutter, &c., and so to prevent those particles being inhaled. The length of the passages which lead to the lungs, the sensibility and muscular apparatus bestowed upon them, and the mucous secretions thrown into them, are the natural means by which foreign matter is arrested and thrown out. But in these artificial conditions of men, insoluble particles are continually floating in the atmosphere which they breathe; these are drawn in and lodge in the lungs, and irritate to disease.

The reader will find that the following extract, from

a paper upon the actions of the windpipe, illustrates the present subject.*

"We read that the trachea is formed of imperfect hoops of cartilages joined by membranes, and that it is flat on the back part for these reasons: that it may be a rigid and free tube for respiring the air; that it may accommodate itself to the motions of the head and neck; and that it may yield in the act of swallowing to the distended œsophagus, and permit the morsel to descend. This is perfectly correct: but there is a grand omission. Whilst all admit that a copious secretion is poured into this passage, it is not shown how the mucus is thrown off.

"There is a fine and very regular layer of muscular fibres on the back part of the trachea, exterior to the mucous coat, and which runs from the extremities of the cartilages of one side to those of the other. This transverse muscle is beautifully distinct in the horse.

"When a portion of the trachea is taken out, and every thing is dissected off but this muscle, the cartilages are preserved in their natural state, but the moment that the muscular fibres are cut across the cartilages fly open. This muscle, then, is opposed to the elasticity of the cartilages of the trachea. By its action it diminishes the calibre of the tube, and by its relaxation the canal widens without the operation of an opponent muscle.

"The whole extent of the air-passages opens or expands during inspiration, and then the trachea is also more free; but in expiration, and especially in forcible expectoration and coughing, the trachea is diminished in width. The effect of this simple expedient is to free the passage of the accumulated secretion, which, without this, would be drawn in and gravitate towards the lungs. When the air is inspired, the trachea is wide, and the mucus is not urged downwards. When the air is expelled, the transverse muscle is in action, the calibre of the tube is diminished, the mucus occupies a larger proportion of the canal, the air is sent forth with a greater impetus than that with which it was inhaled, and the

* 'Philosophical Transactions.'

consequence is a gradual tendency of the sputa towards the top of the trachea. In the larynx the same principle holds; for as the opening of the glottis enlarges in inspiration, and is straitened in expiration, the sensible glottis, by inducing coughing, gets rid of its encumbrance. Without this change in the calibre of the trachea, the secretions could not reach the upper end of the passage, but would fall back upon the lungs.

"Experiments have been formerly made by M. Favier, which, although no such view as I now present was then in contemplation, prove how the action of the transverse muscle tends to expel foreign bodies. The trachea of a large dog being opened, it was attempted to thrust different substances into it during inspiration, but these were always sent out with impetus, and could not be retained. Why the dog could not be thus suffocated is apparent: the tube is furnished with this most salutary provision to secure the ready expulsion of all bodies accidentally inhaled—the air passes inwards by the side of the foreign body, but, in its passage outwards, the circumstances are changed by the diminished calibre of the canal, and the body, like a pellet filling up a tube, must be expelled by the breath."

We have, perhaps, pushed the inquiry far enough; and yet the interest might be increased by observing the manner in which the textures of the ribs are accommodated to variations in the mode of respiration, or to the necessity of the animal expressing the air from the lungs in diving. We have seen how the thorax is expanded in birds to the whole extent of the body, for obvious reasons; and the counterpart of that is presented where the animal, instead of being buoyant in the atmosphere, has to dive into the water and crawl at the bottom—not at great depths, but yet under water, in shallow pools and marshy places. The frog has no ribs; and its mode of respiration shows a complete change from that of animals which breathe with a diaphragm. It has the power of compressing its body, and expelling the air from the lungs; and were it not for this, the animal would remain on the surface of the water as when

cruel boys blow them up with a straw. The crocodile and other saurian reptiles have their ribs accommodated so as to produce a similar effect, and for a similar purpose. Instead of the arched form of the ribs, which we have described as capable of a slight change of figure only, they have ribs composed of distinct pieces, and jointed in such a manner as to enable them to compress the chest into a smaller volume.

We have a sort of exposition of the uses, if not the necessity, of respiration to the voice, in observing by what substitutes sound is produced, for example, in insects, which do not breathe by lungs. And indeed the same consideration suggests the inquiry as to the means by which the atmosphere is agitated, in the same class of animals, in subservience to the sense of smelling.

VII.

THE SUBJECT CONTINUED WITH REFERENCE TO THE CAPACITY OF THE CHEST, AND ITS CONDITION DURING BODILY EXERTION.

We must approach this part of our subject by the consideration of that law of fluids which appears, at first, so contradictory as to be called the "hydrostatic paradox."

Suppose a machine formed of two boards of equal diameter, and joined together by leather nailed to their margins like a pair of bellows: a hole is made in the upper board into which is inserted a tube. Now, if a person mount upon this apparatus when it is filled with water, and blow into the tube, he can raise the upper board, carrying himself upwards by the force of his own breath—indeed, by the power of his cheeks alone. It is on the same principle that, when a forcing pump is let into a closed reservoir of water, it produces surprising effects. The piston of the hydraulic press being loaded with a weight of one pound, the same degree of pressure will be transmitted to every part of the surface of the reservoir that is given to the bottom of the tube, and the power of raising the upper lid will be multiplied in the proportion that its surface is larger than the diameter of the tube. Or, to state it conversely: suppose we had to raise the column of water in the tube by compressing the reservoir, it would require the weight of a pound on every portion of the superficies of the reservoir equal in extent to the base of the piston, before the water could be raised in the tube. If the apparatus which we have described were full of air instead of water, we should witness a similar effect; for all fluids, whether elastic or not, press equally in all directions; and this is the law on which the phenomenon depends. If we blow into the nozzle of

a common pair of bellows, it is surprising what a weight of books we can heave up if laid upon its board.

Understanding, then, that the power of the hydraulic press, in raising the lid, depends on the size of the reservoir, and its relation to the tube; and again, that in pressing the fluid up through the tube, the pressure upon the sides of the reservoir must be the greater the larger the cavity, we can conceive how a glass-blower propels the air into his blow-pipe with great ease, if he blows with the contraction of the cheeks, the smaller cavity; but with an exhausting effort, if he blows by the compression of the larger cavity, the chest. Dr. Young made a calculation, the result of which was, that, in propelling the air through a tube of the same calibre, a weight of four pounds operating upon a cavity of the size of the mouth would be equal to the weight of seventy pounds pressing upon a cavity of the dimensions of the chest.*

* The action of one who uses the blow-pipe is rather curious. The mouth is distended with air, and the passage at the back of the mouth closed; the man breathes through the nostrils, but, from time to time, admits a portion of air into the mouth in expiration. The pressure into the blow-pipe is from the distension and consequent elasticity of the cheeks, occasionally assisted by the buccinator muscle, or trumpeter's muscle, so called because it compresses the distended cheeks. In this way the stream of air through the blow-pipe is kept up uninterruptedly, whilst the man breathes freely through his nostrils.

Let us see how beautifully this hydraulic principle is introduced to give strength in the common actions of the body. We have remarked that the extension of the superficies of the thorax is necessary to the powerful action of the muscles which lie upon it; and these are the muscles of the arms. We must all have observed, too, that in preparation for a great effort, we draw the breath and expand the chest. The start into exertion, and of surprise, in man and animals, is this instinctive act. But unless there were some other means of preserving the lungs distended, the action of those muscles which should be thrown upon the arms would be wasted in keeping the chest expanded. It is here, then, that the principle which we have noticed is brought into play. The chink of the glottis, which the reader has already understood to be the top of that tube which descends into the lungs, is closed by a muscle not weighing a thousandth part of the muscles which clothe the chest; and this little muscle controls them all. A sailor leaning his breast over a yard-arm, and exerting every muscle on the rigging, gives a direction to the whole muscular system, and applies the muscles of respiration to the motions of the trunk and arms, through the influence of this small muscle, that is not capable of raising a thousandth part of the weight of his body: because this little muscle operates upon the chink of the glottis, and is capable of opposing the whole combined power of all the muscles of expiration. It closes the tube just in the same way that the man standing on the hydraulic bellows can with his lips support his whole weight. Thus it is that the muscles which would else be engaged in dilating the chest are permitted to give their power to the motions of the arms.

Some cruel experiments have been made, and, for whatever intended, they illustrate the necessity of closing the top of the windpipe during exertion. The windpipe of a dog was opened, which produced no defect until the animal was solicited by his master to leap across a ditch, when it fell into the water in the act of leaping;

because the muscles which should have given force to the fore-legs lost their power by the sudden sinking of the chest. The experiment is sufficiently repugnant to our feelings; and I need not offend the reader by giving instances in further illustration from what sometimes takes place in man.

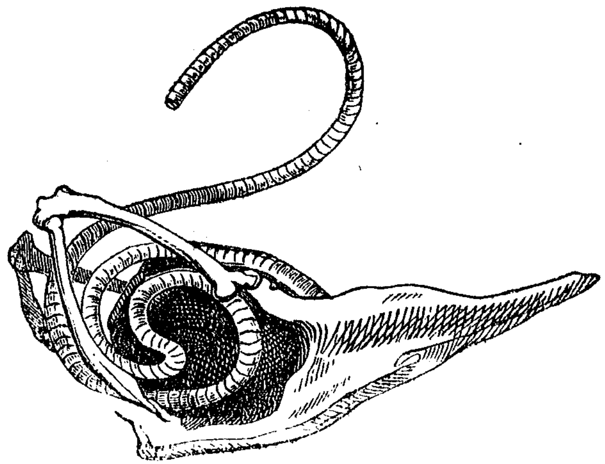
VIII.

THE RELATION OF THE BODIES OF BIRDS TO THE ATMOSPHERE.

The first object noticed in Chap. xvii. is the wing of a bird; and this is given as an instance of *the relation of the animal body to the elements by which it is surrounded.* We entreat our readers' attention to the philosophy of this subject. And let us not be contented with admiring the structure of the feather, or the adaptation of the bones of the wing to their office, but let us go deeper into the inquiry: it is a subject which will reward us.

Let us take it for granted that a creature is to live by the exercise of the same functions with the races of mammalia or quadrupeds, as digestion, assimilation, respiration, &c.; but that it must rise in the air and seek its food by long flights. What are the circumstances necessary to this new condition? Is it not obvious that the creature must be specifically lighter or more buoyant in the atmosphere?—that instead of its muscular system being divided and directed to the movement of four extremities, it must have its strength principally directed to the wings, that it may extend them and be able to raise its body upon them? Let us then see how this is accomplished, and how the original animal economy is interwoven with an entirely new machinery of motion.

The first object will be attained by enlarging the body of the bird, without increasing the weight in anything like the same proportion—and one very obvious means will be found in extending the trachea or windpipe. In examining the tame and wild swan, the most careless observer will detect the provision for flight in the latter, by the conformation of the windpipe which is curiously convoluted within the sternum or breast-bone.



This sketch from the male crane will illustrate what we mean. The light and hollow air-tube fills a space in the interior of the bone, by which the surfaces are extended for the attachment of the muscles of the wings, and thus two objects are attained through it.

In attempting to explain the reason of such deviations from the common forms of parts, we are liable to fall into the same mistakes as we find occasionally in commentators on the Sacred Volume. Were we seeking for the varieties of the organs of voice, we might here start to the conclusion that we had found in the animal body a complex instrument resembling a trombone or Siberian hunting-horn; but by further inquiry we should discover that some of those birds that have the most complex and varied windpipe have no cry at all.

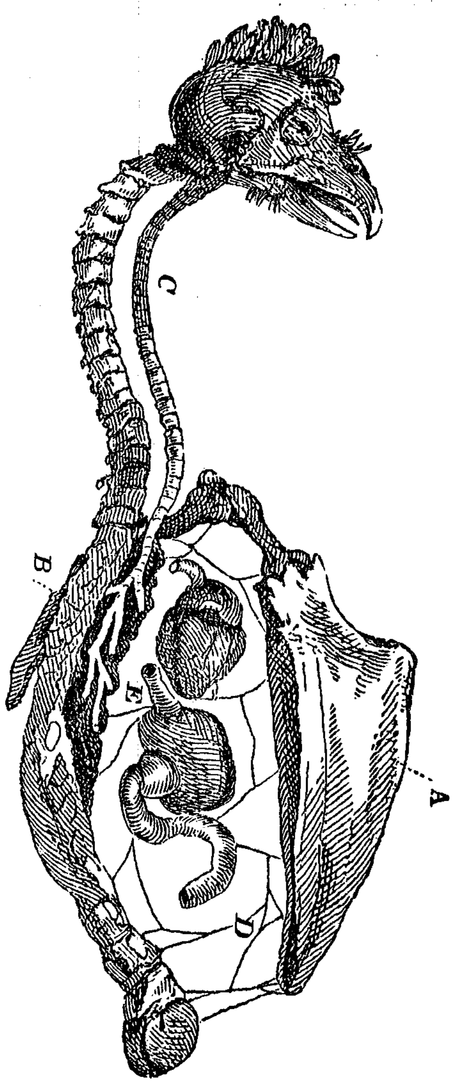
But there is a still more curious provision for the extension and magnitude of the body of a bird, independently of weight. In birds the air does not only pass into their lungs, but through them, so as to fill a series of air-cells, composed of fine membranes which are interwoven with all the viscera. The heart is surrounded by such a cell. Two great cells are attached to the liver, and in the same manner are all the viscera of the abdomen interspersed with air-cells, and these all communicate. The air thus admitted into the interior of the body, extends even into the bones. Naturalists have mistaken the end of this structure when they have represented it as a developement of the respiratory organs. It is not to make the function of respiration more perfect that the air enters so extensively into the body; as a proof of which, the air in the bones of the head is supplied through the nasal cavities and Eustachian tubes, independently of the lungs altogether.*

Mr. Hunter has shown us, that in many birds the internal air-cells communicate with the exterior cellular membrane, especially in the neck and axilla, which marks an analogy with the air-cells under the skin of the bat. Winged insects, too, have their bodies extended by air-cells communicating with their respiratory apparatus. These facts sufficiently evince the object of Nature in this extension of the air-cells: that it is not for the purpose of breathing, but for enlarging the volume of the body without increasing the weight.

We must observe the very peculiar mechanism of the bird's respiration. The breastbone or *sternum*, A, runs the whole length of the animal's body, and the great central spine of that bone called the *keel*, rises from it, so as to give lodgment and attachment to the great muscles of the wings. It will be easily understood how naturalists distinguish birds of passage by the size of the keel (crista), since its greater prominence implies strength of wing for long-continued flight. Under the breast-bone, and between it and the back-bone, we perceive the space occupied by air-cells. The lungs, B, lie behind; and by the motion of the bone A, like a great bellows, the air is drawn through the lungs, and through the windpipe, C, into the cells D, E; at once effectually oxygenating the blood in the lungs, and renewing the air within the recesses of the body.

The next thing remarkable is in the vertebræ of birds —for the backbone is in its constitution unlike that of

* Mr. Hunter's 'Animal Economy.'



man or quadrupeds. The back is firm and the caudal extremity loose and moveable. The first is obviously intended to give a fixed origin to the muscles of the wing, and the second to afford motion to the tail. It is by the wings they raise or propel themselves, and by the tail they direct their flight. We need hardly add that there is a change in the centre of gravity compared

with that of animals; in birds the centre is between the wings.

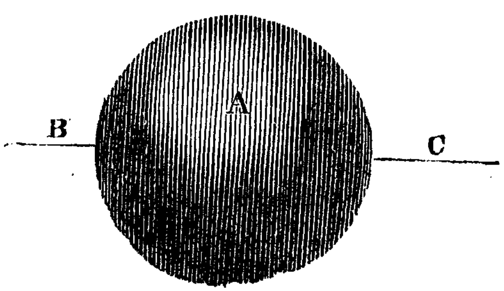
If our reader has followed us in these details, he will acknowledge that there cannot be a more curious instance of a change and adaptation of the whole system of the living body to the external elements, than is to be found in the system of birds.

IX.

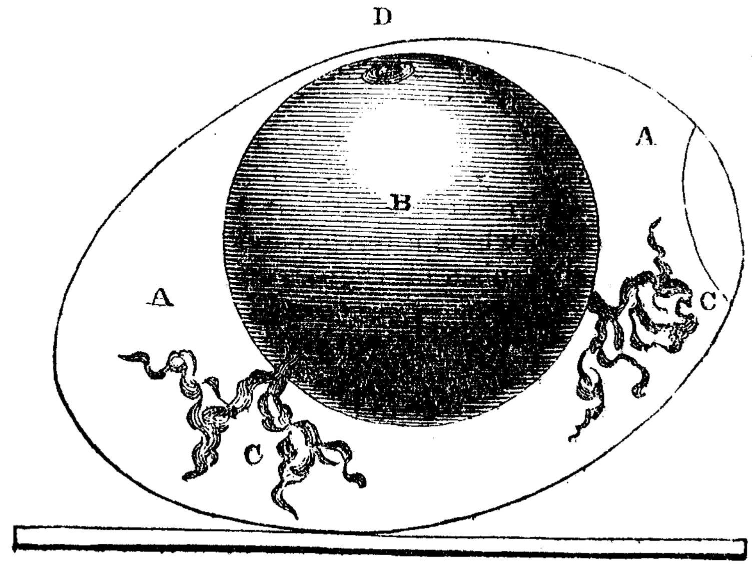
MECHANISM OF THE EGG, OR REVOLVING OF THE YOLK.

THE illustration used in the Preliminary Discourse, of the manner in which the cicatricula, containing the chick within the egg, is presented to the breast of the hen, requires the following diagrams in explanation.

When we hold an egg steady, and chip it at the upper part, we find the yolk close to the shell; and on its upper surface a pale vesicle, the cicatricula, which contains the embryo chick. When the hen sits, the heat of her body developes the action of the living principle in the embryo, and on the second and third day a little zone of blood-vessels appears; these vessels run towards the embryo, and carry nourishment to it; and day by day we may watch its sensible growth. From the delicacy of this action we may perceive how necessary it is that the embryo at this early period should be close to the breast of the hen, and not at the cold bottom of the nest. We shall now see how it is accomplished. The yolk is a globe of nutritious matter, and the little vesicle with the embryo is involved in the surrounding membrane, and consequently, as we have said, is at the surface of the globe. If this globe had the axis of its revolution thus, in the centre, it would not



move with the change of the position of the egg. But the axis being below the centre, it must turn round with every change in the position of the egg, whether the globe be heavier or lighter than the surrounding white: were it heavier, it would revolve so as to bring the embryo to the lower part of the shell—were it lighter, to the upper part of the shell. It is lighter, and the matter stands thus:



[This beautiful apparatus has not been understood; and in the last publication which touches on the subject the yolk is supposed to be heavier, and to hang upon the chalazæ.]

A A, is the white of the egg; B, the yolk; C C, the treddles or chalazes; that tough matter which we find in eating an egg little boiled. Each of these bodies is connected with the white, and attached at a point to the yolk. The yolk being as it were anchored at these two points, and the attachments being below the centre, and the yolk being lighter than the surrounding white, it revolves like a buoy, and the cicatricula containing the embryo D is thus kept always uppermost.

If "the chicken roosting on its perch be related to the mass of the globe and the earth itself," as our author has affirmed, what may we say of the revolution going on within the egg?

X.

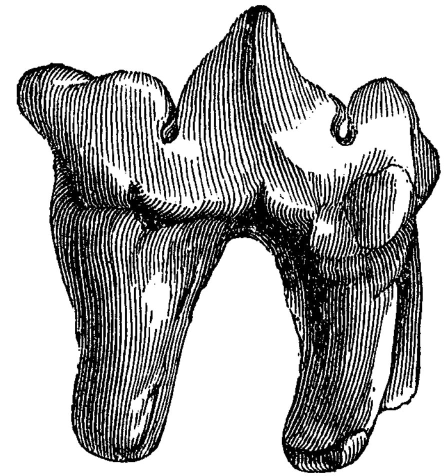
OF THE TEETH OF ANIMALS—THEIR MECHANICAL PROVISIONS.

THE teeth form a subject of much higher interest than will at first be readily imagined. There is no part of an animal body where 'contrivance' is more distinctly demonstrated, or in which a resemblance is more obvious between the mechanism of engines and the provisions in the animal mechanism. Suppose an instrument were to be ingeniously contrived to cut like an adze, or to divide like a pair of shears, or to grind like a mill-stone, or to hold like a mousetrap,* or to tear,—what, after a period of working, would be the condition of these machines? Would not the edge be blunted—the sharp points become rounded—the grinding surfaces smoothed?—and would not the teeth of the machine be driven deep into the sockets, and so render it wholly useless? But nothing of this kind takes place in the teeth of animals. They are perfect for their purpose, and, if duly exercised, last the natural term of life, however the period of natural decay may vary in different animals.

To commence with the manner in which the teeth resist pressure into the jaw. If we look to the teeth of the lion, we find their roots conical and socketed, as if a nail were driven in; and so it is in the remarkably strong teeth of the hyæna.

Now these animals have powerful muscles, closing the jaws with a force to break the strongest bone. How is it, then, that the teeth are never pressed deeper into the jaw? For undoubtedly this would be the effect in an

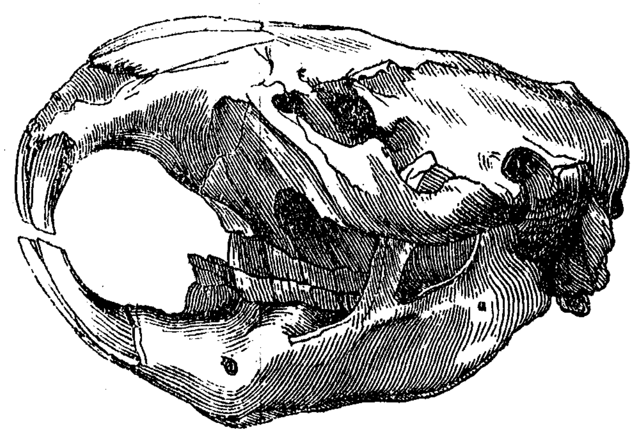
* As in the gullet of fishes.



[The figure represents the back tooth of the Tiger's jaw, which closes like the blade of scissars.]

engine so constructed by man's ingenuity. The reason is, that there is a living property in the teeth and jaw, by which the former are made to protrude from their sockets, in proportion to the pressure to which their crowns, that is, their exposed parts, are subjected. It is very remarkable that the teeth during their period of growth, notwithstanding they are exposed to the pressure of mastication, will ascend or protrude more and more out of the jaw; and when fully grown, they will remain stationary and on a level, if subjected to the natural pressure of mastication; but without this they will rise too high, project, and at last fall out. It is on this principle, that if we lose teeth in one jaw, we lose them in both; and there are no means of preventing the loss of these, but by such mechanical substitutes as shall restore them to their due exercise. And yet Nature modifies the law with perfect ease, and, as it were, at will. Let us take an example:

The front teeth of the horse are called "nippers;" they meet, and crop the herbage. As the horse is a vegetable feeder, he must grind with his back teeth, and during this act the front teeth must participate in the grinding motion. We shall presently see how they are protected against this attrition. But in the ruminant animals, those which chew the cud, there is a necessity for a more thorough grinding of the food, whilst at the same time the front teeth must preserve their edge. For this purpose the teeth are wanting in the fore part of the upper jaw, and there is only a cushion, which embraces and holds the grass against the edge of the lower teeth, so that it is cut, as with a sickle, by a smart twitching motion of the head. Thus the front teeth undergo no attrition. Now, although there be no teeth in the upper jaw, those below do not rise or become loose, as they certainly would in man, or in any other animal, not of the class of ruminants. This reasoning will be more satisfactory than the statement at p. 225 of vol. ii. Two objects are here attained; first, that the cutting teeth are preserved sharp; and, in the second place, these teeth differ in their condition from ours, since they do not rise in consequence of wanting opponents.



[The figure represents the skull of the Beaver, to show the nature of their cutting teeth.]

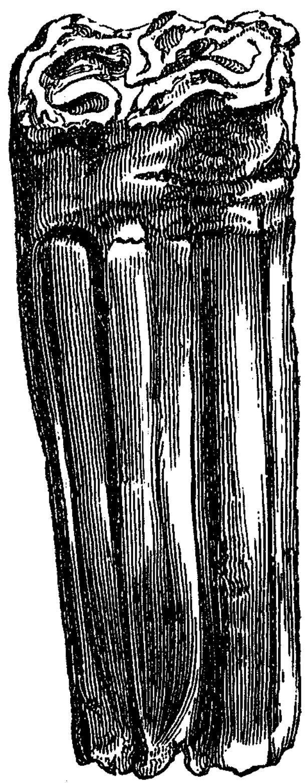
In the class of rodentia or gnawers, the front teeth must cut with a sharp edge. We know how this is contrived in the tool of the carpenter; and we know also that he must from time to time apply his chisel to the grindstone. The front teeth of the beaver, the porcupine, and the rat, are sharp and yet not blunted by use;

the bone of the tooth is the densest possible, consistent with the material; but were the whole tooth of the same material, it would be ground down uniformly, and the original form of the instrument would be lost. Accordingly, a different substance, the enamel, which yields more slowly to attrition than the bone of the tooth, is, as it were, let in on the anterior surface of the tooth. The consequence is, that the enamel stands up sharp and exposed, so as to protect the bone of the tooth, and to give the surface which is worn down a certain shape, viz. that original shape suited to cut like an adze. The attrition and the arrangement of the material of the tooth so far correspond, that the cutting form is preserved, however much the surface may be worn down.

Now, a tooth cannot grow; and as we have seen that it is wasted by friction, how is the cutting edge to retain its place? When the steel plate of the carpenter's plane is forced in by repeated taps with his hammer, he projects the sharp edge, and when it is elevated above the plane in a just degree, he fixes it there by a smart blow on the wedge; but the cutting edge of the chisel-like incisors of the rodentia is still more finely adjusted.

In the first place the tooth is very long, extending the whole length of the jaw, and it is of a curve not easily described, not partaking of any section of a cone; still it is so adapted, that the cutting edge meets its opponent tooth, and, although incessantly wasted, it is accommodated to the growing jaw. We have said that a tooth does not grow. It does not grow like a bone, but sometimes additions are given to it at the root; such is the case in this class of animals: the tooth of the gnawer is thus pushed on along the jaw, owing to the growth taking place at its root and in its proper curve; so that the cutting edge is protruded in proportion as it is wasted in the process of attrition and sharpening. This is a mode of growth which takes place in no other animal's incisor tooth.

Let us now observe how the grinding surface of the tooth of an herbivorous animal is composed. It must be rough or irregular, so as to catch the grain. A smooth millstone, for example, would not bruise the grain into meal. The burr-stone, accordingly, is sought for the nether millstone. This stone contains small portions of feldspar, imbedded in a softer material; and thus, however the surface may be ground down, the harder material, by yielding less easily to friction than the softer, projects above the general level, and preserves a roughness of the surface even whilst it is yielding. It is exactly so with the tooth of a graminivorous animal. It is composed of alternate layers of the hardest bone, or rather of ivory, and a denser material still, the enamel. The consequence of this inequality in the composition is, that notwithstanding the surface of the tooth is worn down, the roughness is preserved.



[The figure represents the molar tooth of the Horse, and exhibits the roughness of its upper surface, and the depth of the body of the tooth in the jaw commensurate to the pressure it bears.]

There is something curious, too, in this irregularity, showing that it is as far as possible from accident. The lines of enamel which stand up differ in their arrangement according to the motion to be given to the jaw. In the horse and cow these ridges run parallel with the jaw, and consequently lie across the direction of the motion of chewing, which is from side to side. In the rodentia, on the other hand, the line of the enamel of the grinding teeth runs transversely to the jaw; and in mastication the jaw is drawn backwards and forwards, not laterally. This original composition of a grinding tooth is, therefore, superior to the best millstone. The roughness, which is so like a thing accidental, is found to proceed from an arrangement in accordance with the motion of mastication. It might, in like manner, be easily demonstrated that there exists a similar accordance with the form of the jaw and with its articulation; but the instances already given of adaptation may suffice.

Before leaving the subject of the provisions against the wasting of the teeth by friction, there are one or two circumstances of a very interesting nature to be noticed. The elephant is a graminivorous animal, and requires to grind its food very thoroughly. What then must be the provision in the grinding tooth of this animal to withstand the power of its jaws? We find the teeth, in fact, formed of three substances, and, we may say, of a structure superior to the teeth of the lesser graminivorous animals, of course admirably suited to resist the action of chewing. But there is a circumstance peculiar here. Although the matter of the tooth once formed does not change, an alteration in the position of the tooth in the jaw may produce a similar result. When the great grinding tooth of the elephant appears first above the jaw, the anterior corner only projects; but as that becomes worn down, the tooth, by revolving on its centre, presents in slow, but regular succession, more and more of the surface, guarded with new plates of enamel, until it is at last worn to the roots. Here, then, we have a new and extraordinary provision against attrition in the teeth of an animal which lives to a great age. The structure of the tooth itself has a very large proportion of enamel, in dense and regular ridges; but as if the material of the teeth could be brought to no greater perfection to withstand the chewing, it is "contrived," for we have licence for such language in our author, that the tooth itself shall undergo a revolution, not being simply elevated from the jaw, but turning on an axis.

There are other modes in which Nature counteracts the wear and tear of the engine; and the provision which we have now to mention supplies not only a substitution of more perfect teeth for those that are injured, but teeth of a size as well as form suited to the growing jaw. In the crocodile, for example, the teeth are conical and sharp; but if not worn, they must be torn away, and there is a necessity for a succession. It is thus provided: under the exposed tooth there is another one lodged, of the same shape; and under that a second and a third. Each tooth, as it is deeper in the jaw, is larger in its base, and longer and stronger. So it happens, that when a tooth is torn off, it is only the uncapping of a sharper and a stronger tooth.

The same end is attained differently in other creatures. In the rays, such as the skate, and in the shark, the succession of the teeth is still more curiously managed. The jaws resemble a part of a cylinder, studded with many rows of teeth. The teeth of the outermost row being in use, are liable to be torn off or worn down; when this occurs, their places are supplied by a revolving of the solid base on which the teeth are studded, and the posterior ranges advance in succession. Here, then, we not only find sharp and cutting teeth, like those of a saw, but, corresponding with the boldness and voracity of the animal, we see a provision for their rapid renewal.

It is interesting to see how the same class of parts may be modified, and yet retain their original destination of supplying the stomach with food, and preparing it for digestion. What teeth could we suppose suited for the whale? Now the largest species of whale feed upon a small molluscous animal which abounds in the northern ocean. The teeth are here, we may say, converted into

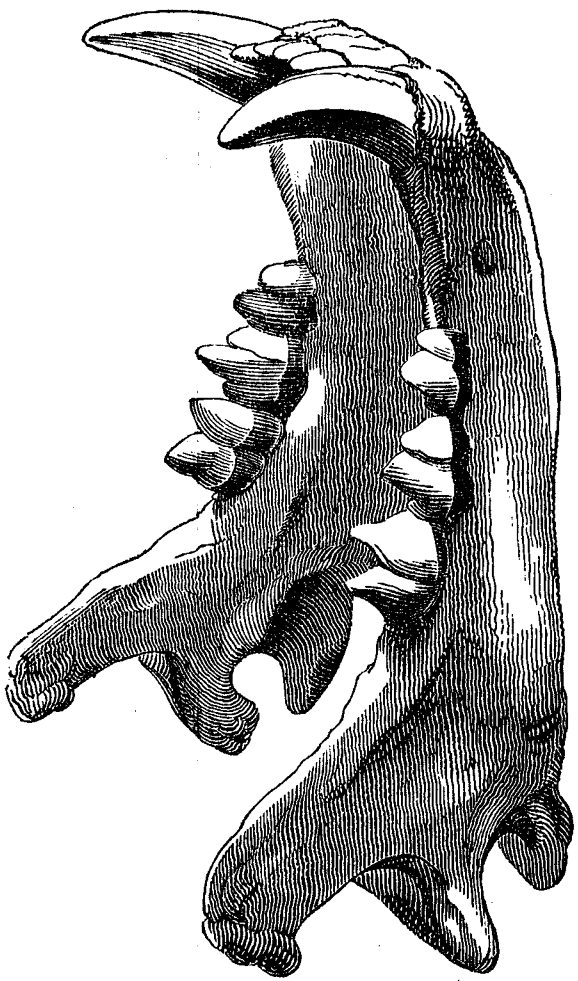
a substance like horn, with which we are familiar under the name of whalebone. They consist of plates of this whalebone attached to the upper jaw, and placed in rows on the outer margins. Their loose edges terminate in a fringe, as if the plates were split and teased into shreds; and this is undoubtedly for the purpose of retaining the small fry, while the water is drained through their interstices.

In this curious apparatus there is, of course, no necessity for great strength in the jaw, nor for very powerful muscles to move them. The head of the animal needs not, therefore, be denser in its texture, nor less buoyant than the rest of the body. What would be required if any of the species had jaws or teeth at all corresponding with their size? They could not lie horizontally; their head would, from its weight, be depressed, and their tail elevated towards the surface of the water. We need not, however, strain our ingenuity to say what would be required, for Nature has demonstrated how this defect is to be remedied. The spermaceti whale, which has teeth, has also cavities in its head filled with a material much lighter than water, the spermaceti; and this counterpoises the weight of the teeth and jaws, and restores the equilibrium of this cetaceous animal.

We have, perhaps, said enough on this part of our subject. But as we have seen how strangely the teeth vary, to be adapted to their office of cutting and grinding, we may observe that they are sometimes adapted to different purposes.

The common classification of the teeth is into incisors, canine, and molar or grinding teeth. Let us take our example from the canine teeth. In man they are of great length and strength; their fangs project deep into the upper jaw; they are called the eye-teeth, and they tend to sustain and give strength to the range of the incisors. In the carnivorous animal they are called "laniarii;" they are for tearing and holding, for which purpose there is a correspondence between them and the hooked claws.

The tusks of the elephant are of this class, and between these the tender trunk is protected. In the boar the canine teeth project, and become powerful instruments, not for biting, or holding, or tearing, but for rending, or rather cutting; that is, the whole force of the animal in its rush is directed to give effect to the tusk. So little are the tusks calculated for biting, that the tusk of the lower jaw closes in upon that of the upper jaw, so as to support its base, and to give it strength commensurate to the power and impetus of the animal. But we must not suppose that the tusks are solely for the



[The figure of the lower jaw of the Tiger]

purpose of offence. The strength and the power of the neck of the boar is mainly for the purpose of ploughing up the earth and rooting up herbs by means of its tusks.

In some animals, as the babyroussa, this tooth rises and twists, so as to make it at first sight appear useless. Certainly the tusk is neither for holding, tearing, nor masticating; yet it is not useless. This animal escapes from his enemies by the facility with which he rushes through the brushwood; and these teeth are curiously calculated to bear aside the branches and to protect the eyes.

In other animals, as the walrus, the canine teeth of the upper jaw become tusks, but project in an opposite direction to those of the elephant. They enable the animal to raise itself out of the water, by holding on upon the rock or iceberg, as the parrot steadies himself by the bill.

XI.

THE SUBJECT PURSUED WITH REFERENCE TO THE FORMATION AND GROWTH OF TEETH.

SEEING how admirably these instruments have been adapted to their several uses, the reader must be curious to know how they are produced—how they are manufactured with so fine a "prospective contrivance." Three different substances are exposed on making the section of a tooth; viz. ivory, or the bone of the tooth—the enamel, which is very hard, and breaks with a vitreous fracture—and a substance differing in some respects from both, and which English anatomists have called crusta petrosa, and Cuvier cement. These three substances are not formed in every tooth. Some teeth consist entirely of the bone or ivory, as those of the porpoise and bottle-nosed whale. In man, and in the carnivorous animals, the bone is covered with enamel, and in the graminivorous and ruminant animals, all three substances are found.

In the chapter on bone, it has been shown that its texture must be loose to admit blood-vessels; for bone is nourished and undergoes changes through the influence of the circulating blood in it. But the almost stony density of the teeth does not admit of circulation within them; yet they possess life, and through that principle are in union with the gum and jaw. A dead tooth, however pure and perfect, when thrust into the socket of the jaw, remains there no longer than would a peg of wood or of metal. It causes inflammation and pain, and is thrown out.

It would be a difficult question for those who consider

life to be the result of organization to solve, how a principle of life should exist for a term of years, giving rise to a sympathy and union with the jaw, in a part like the bone of a tooth, which has neither what they call organization nor any circulation of blood in it. Here we have one of those inscrutable qualities of life which makes physiology a science distinct from all others; and it is an example of there being adaptations far more admirable than merely mechanical appliances.

But we were about to show how the different portions of a tooth are formed. In the jaw of the young animal a sac is discovered, which contains the rudiments of the tooth. On opening the sac, we think we see the tooth, but it is only a body of the form of the crown of the tooth, and is soft to the touch. This is called the *pulp* of the tooth; although pale at first, at a stated period it becomes full of blood, and then the bone of the tooth begins to be formed; and now, on touching it, we can lift from it a delicate shell, which is at once of the form of the pulp, and of the perfect tooth. The process thus begun is completed by the secretion of successive strata from the surface of the pulp, until the bone of the tooth, which was at first a mere scale, becomes a dense body, with a small cavity and tube leading to it; and the pulp, which was of the size and shape of the tooth, shrinks to a mere shred, containing a nerve and vessels.

Thus the original use of the pulp is changed: but it remains, serving an important purpose; for by sustaining a sensible nerve within the tooth, it extends a degree of protection to it. The teeth are sensible to what we masticate; they are sensible to the smallest particle of sand, and so are they to the degrees of heat. This sensibility is necessary to their protection, and to the continuance of their vitality, yet the sensibility is not in the substance of the tooth, but in the nerve within; and the density of texture of the tooth becomes a medium through which both mechanical vibration and heat are readily communicated to the nerve.

We have seen how the bone of the tooth is secreted by the pulp. The enamel is formed differently. The sac, which covers the whole pulp and rudiments of the tooth, has a fine organization, as displayed by the art of the anatomist, and its inner surface throws out a fluid which, falling on the surface of the bone of the tooth (already formed by the pulp), there concretes, or undergoes a species of crystallization, and hardens into enamel.

The difference between the bone and enamel of a tooth, that is, between what is formed by the pulp and by the sac, is shown by a very simple process. When a tooth is immersed in diluted nitric or in muriatic acid, the enamel is dissolved with effervescence, and is completely carried away; but when the earth of the bony part is dissolved, it leaves behind it a cartilaginous matter, which constituted a part of the bone of the tooth. In its chemical composition the bone of the tooth resembles the bone of the skeleton, though not strictly and anatomically, as it wants the vascularity of true bone; it is therefore, with more propriety, called ivory.

We have still to explain how the compound teeth of the vegetable feeders are formed. Now, if we comprehend the means employed in the simple tooth, we shall have little difficulty in understanding this. The pulp is divided, and consists of parallel layers joined below, but free above, and with considerable interstices. These divisions or processes of the pulp secrete the ivory upon their surfaces, by which, of course, plates of this dense material are formed on each side of the soft processes or tongues of the pulp. There will therefore be double the number of plates of bone that there are processes of the pulp.

Each plate of bone must be covered or invested with enamel. This is effected by folds or projecting processes of the capsule or sac, which, hanging from above, intervene between the plates of bone, and there perform their peculiar secretion, depositing the enamel. But it would appear that these processes, becoming at length tightly embraced by the plates of enamel which they have themselves secreted, throw out a less perfect material, as it were; this is called the *crusta petrosa* or cement. When the tooth thus formed rises above the gum, and when attrition wears down a part of it, the interstices caused by the wasted processes of the septa of the sac are exposed, and the food is crammed down into these crevices, and then on making a section of the tooth we may discover four substances, ivory, enamel, crusta petrosa, and foreign matter, in alternate layers.

Now, contemplating the slow formation of the teeth whilst yet deep in the jaw,—their curious mode of growth, adapted to the form of the jaw,—the articulation of the jaw with the head,—the position and powers of the muscles that are to move the jaw, with the means to be employed by the animal in gathering, masticating, and digesting its food,—we can desire no more absolute proof of prospective contrivance and design. Were we to seek further, we have only to compare these mechanical appliances with the instincts and propensities of the animals.

There is but one thing more worthy of attention in the teeth, than their mechanism, we mean their vital properties. Is it not a wonderful thing to see the jaw of the infant with a ridge upon its gums, harmless to the nipple; and then at the time when the powers of digestion vary, and become suited for stronger food, to find sharp teeth arise, a range of them having been provided, which when fully developed are in exact accordance with the size and form of the jaw of the child? Can any one tell us how these teeth should waste at an appointed time, to give place to others of stronger form and of larger dimensions conforming to the adult jaw-bone? The phosphate, carbonate, and fluate of lime, do not differ in these milk-teeth, or deciduous teeth, and in the adult teeth; yet, by a secret process of decay, the first fall out in the period of childhood, and the second last a long lifetime.

XII.

OF THE MOUTH.

Our author has said that everything in the structure of the mouth is mechanical, and he has given a very attractive view of the varieties of the mechanism in the mouths and bills of animals. But so far from exhausting the subject, he has left some of the most interesting particulars untouched. In man, the mouth is not flat because he has hands, but because it is a part of that apparatus, which is the most curious and important of all the bodily structures,—the instrument of speech. In that light we shall presently take it up separately, not doubting that it will reward the reader's attention.

Let us, in the meantime, consider some of the common properties of the mouth; and first, of the most obvious parts, the lips. Nothing serves better to make us appreciate the blessings we enjoy, than examining the organization of a part which, from its familiarity, and the absolute perfection of its action, we neglect or think meanly of. The lips receive the food, and aid in mastication; they are a principal part of the organ of speech; they are expressive of emotion; they are the most acutely sensible to touch. But all this never moves our surprise or admiration.

If we know anything of muscularity, we must presume that there is a concourse of fine muscles converging to the lips and surrounding them. But what gives the lips their sensibility? This was a question early suggested to me in my investigations on the nerves; when experiment showed that one nerve went to the lips for sensation, and another for motion. The vermilion surfaces of the lips possess their exquisite sensibility through minute and de-

licate villi, into which the extremities of the sensitive nerve are distributed: and these, being covered only by a cuticle the most thin and transparent, afford the ready instrument of touch. We see how the child uses the lips, as giving him his first information of the qualities of bodies.

It is certainly an unexpected thing to find that two organizations totally distinct, combined in the lips, should be necessary to the simplest act. If the nerve of motion be cut and has lost its function, the animal puts its lips to the grains it feeds upon, but cannot gather them. If the nerve of sensation be injured, the animal presses its lips to the food, but wants the sensibility by which the motions of the lips should be directed. These facts show that whilst sensibility and motion are distinct faculties and depend upon different nerves, they are necessarily combined for so simple an act as taking the food into the mouth. We thus daily see that in paralysis, sometimes one property is lost, sometimes another; a circumstance most important to the physician.

As connected with our present subject, it is a strange thing to see that, whilst a person may have every capacity for motion in the lips and tongue, he will have the morsel remaining in the mouth without knowing it. The first instance I found of a defect in the lips exactly similar to that produced by cutting the nerve of sensation on one side of the face, was in a gentleman who, being under the hands of his dentist, had the nerve of sensation hurt by the pulling of a tooth: and having a glass of water given to him, remarked that the glass was a broken one: the fact being, that the portion of the tumbler in contact with one half of his lips was not felt at all, which gave him the same sensation as if a bit of the glass had been broken away.

We might show, in the lower creatures, an infinite variety in the forms of the mouth; but even in the mammalia, we may perceive that the lips are projected, and have a power almost like that of the hand. The horse has great power in his lips. The camel, the elk, but more especially the rhinoceros, have a still greater mobility, and the latter has a very fine sensibility in the hook-shaped extension of its upper lip: the snout of the tapir and the trunk of the elephant belong to the lips, rather than to the nostrils. We have the least equivocal proof of this, in their supply of nerves, which are only an enlargement or prolongation of those nerves which in man go to the lips. Nay, we may state a fact, perhaps unexpected to the reader, that the whiskers of animals of the cat tribe have entering into their roots branches of the same nerve which gives sensibility to the lips; and the palpa and tentacula in the lower classes of animals, as the crustacea and insects, however different these organs may appear, are known to belong to this order of parts, by the same proofs, their supply of nerves.

We might be tempted here to speak of the bills of birds, had they not already attracted the attention of our anthor. We shall, therefore, rather fortify his conclusions by attention to the structure of the tongue. The human tongue is, no doubt, the most admirable of all the organs. We might have very obvious proofs of intention and adaptation in the long rough tongue of the ox, or in the still more curious and active tongue of the camelopard, or in the tongue of the insectivorous animals, the bear, the chameleon, and ant-eater, or in the variety of curious instruments, darts or saws, sheathed in the bills of insectivorous birds. But we ourselves have an organ, however apparently simple, finer than all these. The human tongue, containing muscular fibres in every possible direction, and round, soft, and mobile, is less admirable as an organ of mastication, of taste, or touch, than as the organ of speech, modulating with every possible variety the sounds issuing from the windpipe. On the upper surface of what is termed the dorsum of the tongue, there are rough papillæ which in some measure correspond with what we see in animals: they are subservient to the taste. Some of them have a mushroom-like top, and a stalk projecting from the bottom of a little hollow, and there the sapid particles of the food lodge, and prolong the enjoyment of the palate. But in the organization of the tongue there is one minute point of structure more curious than

all the rest. When the papillæ are examined with a magnifying glass, there are seen certain small bodies, consisting of a grey sheath, within which there is a little red point; and this point is capable of erection, thus projecting and becoming the organ of taste. It is so erected when the morsel is in the mouth, or when we are in the immediate anticipation of food. There are other more minute processes studding the surface of the tongue, and these contain the extremities of nerves which are sensible to touch. It must surely, therefore, be considered an admirable thing to find so many faculties seated here, each with its appropriate organization, and each most curiously connected with other structures—that we should have the power of mastication, of deglutition, of modulation of the voice, the senses of taste and of touch, concentrated in one apparently simple organ.

Not to speak of other relations, can there be any better proof of design, than the effects of the excited sensibility of the tongue? No sooner have these gustatory points of nerves been excited, than there is poured out into the mouth most abundantly, by four distinct tubes, the saliva, that fluid * which facilitates mastication, and directly prepares the food for the action of the stomach. And however well we might imagine such a supply of fluid to assist deglutition, this is not all that is here done in preparation; for whilst the morsel is moved by tongue, and lips, and jaws, an appropriate fluid is collecting in what appear to be mere irregularities in the back part of the throat, but which are, in truth, so many receptacles, that, pointing towards the stomach, give out their contents as the morsel passes.

There is one curious circumstance which we may

* We presume that the fluid is chiefly useful in mastication, as the glands are large, and the fluid most abundant in animals that chew the cud. In all, these glands are so disposed as to receive gentle pressure from the motion of the jaw; so that, whilst their vascular apparatus is excited by the sensibilities of the tongue, the fluid is urged from the ducts by the pressure of the jaw and muscles which move it. The fluid itself is neither acid nor alkaline.

notice before quitting this subject. Eating seems always to be an act of the will, and attended with gratification. It is well known that the operation, or what is very nearly the same, may go on within the stomach, without any outward sign at least of pleasure. The gizzard (with which we are most familiar in fowls, though it be, in fact, found in the vegetable feeders of the different classes of animals) is correctly enough described as an organ of mastication, in which there is an incessant and alternate action of opponent muscles, as in the motions of the jaws. In the stomach of the lobster we have not merely the muscles of mastication, but the teeth also: so that it appears the function may be performed altogether internally, and without the volition, and probably without the sensations, that accompany the offices of the mouth. We mention this, as drawing the reader to comprehend that many organs may be in operation in the internal economy, without our consciousness.

Our author, with much propriety, from time to time, adverts to those changes in the organization which accommodate the animal to new conditions. Now, in terrestrial animals, the act of swallowing must be accommodated to the atmosphere; but if the animal lives in water, and still breathes the air, the structure of the parts must be changed. The crocodile seizes its prey, and descends into the water with it. Its power of descending does not, as in the fish, result from compressing the air-bladder: but is owing, as we have shown, to a provision in its ribs and lungs. Unless the crocodile could expel the air from its lungs in a greater degree than the mammalia are capable of doing, it could not crawl upon the bottom, nor retain its place there without continual exertion. There is an adaptation to this mode of destroying its prey, by carrying it under water, in the mouth, as well as in the thorax and lungs. The crocodile has no lips; it lies on the shore basking with its mouth open, and flies light upon and crawl into its mouth. Against these the air tubes are protected, not

by the lips and sensibility of the mouth, but by an apparatus which separates the mouth from the throat and windpipe. This partition between the cavities is necessary when the animal seizes its prey: for as it plunges under the water with open mouth, the air tube must be protected against the ingress of the water. For this purpose, there is a transverse ridge, arising from the body of the bone of the tongue, which raises a duplicature of the membrane so as to form a septum across the back part of the mouth; whilst the curtain of the soft palate hanging from above meets the margin of the lower septum, and they form together a complete partition between the anterior and posterior cavities. Thus the animal is enabled to hold its prey in the open mouth, without admitting the water to the air passages.

With these observations, we hope the reader will return to peruse, with increased interest, the conclusions so well stated by our author, vol. ii., p. 110.

XIII.

OF HUNGER AND THIRST.

For very sufficient reasons, we have preferred taking the illustrations of design from the mechanical structure of the body. We may now introduce some instances from the living properties, the propensities and appetites.

Hunger and thirst are in truth senses, although the seat or organ is not easily ascertained. The wants, and desires, and pain accompanying them resemble no other sensations. Like the senses, they are given us as monitors and safeguards, at the same time that, like them, they are sources of gratification.

Hunger is defined to be a peculiar sensation experienced in the stomach from a deficiency of food. Such a definition does not greatly differ from the notions of those who referred the sense of hunger to the mechanical action of the surfaces of the stomach upon each other, or to a threatening of chemical action of the gastric juice on the stomach itself. But an empty stomach does not cause hunger. On the contrary, the time when the meal has passed the stomach is the best suited for exercise, and when there is the greatest alacrity of spirits. The beast of prey feeds at long intervals; the snake and other cold-blooded animals take food after intervals of days or weeks. A horse, on the contrary, is always feeding. His stomach, at most, contains about four gallons, yet throw before him a truss of tares or lucerne, and he will eat continually. The emptying of the stomach cannot therefore be the cause of hunger.

The natural appetite is a sensation related to the general condition of the system, and not simply referable to the state of the stomach; neither to its action, nor its emptiness, nor the acidity of its contents; nor in a

starved creature will a full stomach satisfy the desire of food. Under the same impulse which makes us swallow, the ruminating animal draws the morsel from its own stomach.

Hunger is well illustrated by thirst. Suppose we take the definition of thirst—that it is a sense of dryness and constriction in the back part of the mouth and fauces; the moistening of these parts will not allay thirst after much fatigue or during fever. In making a long speech, if a man's mouth is parched, and the dryness is merely from speaking, it will be relieved by moistening, but if it comes from the feverish anxiety and excitement attending a public exhibition, his thirst will not be so removed. The question, as it regards thirst, was brought to a demonstration by the following circumstance. A man having a wound low down in his throat, was tortured with thirst; but no quantity of fluid passing through his mouth and gullet, and escaping by the wound, was found in any degree to quench his thirst.

Thirst, then, like hunger, has relation to the general condition of the animal system—to the necessity for fluid in the circulation. For this reason, a man dying from loss of blood suffers under intolerable thirst. In both thirst and hunger, the supply is obtained through the gratification of an appetite; and as to these appetites, it will be acknowledged that the pleasures resulting from them far exceed the pains. They gently solicit for the wants of the body: they are the perpetual motive and spring to action.

Breathing, as we have seen, is even more directly necessary to life than food; but to this we are differently admonished. An appetite implies intervals of satiety and indifference. The uninterrupted action of breathing could not be supported by a perpetual desire: we cannot imagine such a uniformity of sensation. The action of breathing has been made instinctive, while pain and the alarm of death are brought as the only adequate agents to control the irregularities of a function so necessary to life. Pain does here what desire and the solicitation of pleasure could not accomplish.

XIV.

THE STOMACH OF THE HORSE.

When we think of the adaptations of animal structure to the different conditions of living creatures, the camel, the ship of the desert, immediately occurs; and no doubt it is highly interesting to observe how this animal is adapted to the sandy waste, in its eye, its nostril, its foot, the cells of its stomach, and its capacity of endurance. But it is, perhaps, more to our purpose to look to our domestic animals, and the most of all deserving attention is the horse.

Of all creatures, the horse has the smallest stomach relatively to its size. Had he the quadruple ruminating stomach of the ox, he would not have been at all times ready for exertion: the traveller could not have baited his steed and resumed his journey. The stomach of the horse is not so capacious, even when distended, as to impede his wind and speed; and the food is passing onward with a greater degree of regularity than in any other animal. A proof of this is, that the horse has no gall-bladder. Most people understand that bile is necessary to digestion; and the gall-bladder is a receptacle for that bile. Where the digestive process is performed in a large stomach, and the food descends in larger quantities, and at long intervals, the gall-bladder is necessary; and there is that sympathy between the stomach and gall-bladder, that they are filled and emptied at the same time. The absence of the gall-bladder in the horse, therefore, implies the almost continual process of digestion; which again results from the smallness of the stomach.

Another peculiarity in the horse is the supply of fluid.

When the camel drinks, the water is deposited in cells connected with the stomach; but if a horse drinks a pail of water, in eight minutes none of that water is in the stomach; it is rapidly passed off into the large intestine and the cæcum. We cannot resist the conviction that this variation in the condition of the digestive organs of the horse, is in correspondence with his whole form and properties, which are for sudden and powerful, as well as long-continued exertion.

XV.

OF THE GIZZARD.

The gizzard is a favourite illustration with our author; he takes it up in Chaps. x. xii. xv. xvi., as the example of compensation, relation, &c.

The bill of a bird has extensive relations both externally and internally. When we see a bird trimming his feathers with his bill, and combing out each feather from the root to the point, we cannot but observe, that admirably as feathers are formed for flight and for protection against cold and wet, they would be inconsistent with the tongue and teeth of the quadruped. The rough tongue would not penetrate to their interstices; nor would the ruder operation of the dog's teeth suit the delicate texture of the quills. The bill, therefore, implies the absence of teeth and of salivary glands. Lips and muscular cheeks are necessary for mastication; and however familiar the operation may be, a chapter might be well occupied to show how cheeks and lips, salivary glands and teeth, must co-operate before a morsel can be swallowed,* and how the derangement of one filament of the nerves supplying these parts disorders the whole train of actions. We have to show, then, how this function, deficient in the bird, is compensated by internal structure.

The gizzard is a fleshy stomach, the exact substitute for the muscles of the jaws, and teeth. Its substance consists of a strong muscle; the dark part of the gizzard being the muscle, and the shining part of it the tendon to which the muscular fibres are attached. There are, in

* See a paper on this subject, in treating of the nerves of mastication, in 'Phil. Trans.' for 1829.

fact, two muscles with a central tendon; it is what anatomists call a digastric or double-bellied muscle. The cavity within this muscle is lined with a dense, rough, insensible coat, and there are always to be found contained in it small stones, generally of quartz, if it be within the reach of the creature's instinct to obtain them. The grains are mixed with these portions of stone; and if we put our ear close to a bird, we shall hear the grinding motions going on as distinctly as the noise of the horse's jaws in the manger. In fact, this digastric muscle or gizzard is equivalent to the muscles of the jaws, and the pebbles are a fair equivalent to the teeth, with this advantage, that when they are ground down, the instinct of the bird supplies it with more. It picks up some small portions of gravel with as much alaarity as it will the grain itself. Some have supposed that this was sheer stupidity in the fowl; but here surely instinct is better than reason.

When we recollect the provisions against attrition necessary to make the teeth last for the full period of the life of a graminivorous quadruped, we are prepared to understand the advantage of this beautiful and simple substitute, which, to so small a creature as the pigeon, gives an equal power over the material of its food, as the horse has with its powerful jaws, and strong grinding teeth.

However, we are but describing a new instrument for grinding, or comminuting the food: yet this alone is not sufficient to supply what was wanting in the mouth; and in passing, we may observe that the gizzard does not exclusively belong to birds. The gillaroo trout and the mullet have gizzards. The toothless ant-eater has a gizzard: it lives on scaly and hard insects, such as beetles; and to assist in bruising them in its muscular stomach, it picks up pebbles like the domestic fowl.

Before the grain descends into this grinding apparatus of the bird, it is deposited in the crop; from the crop it descends, by little and little, into the cardiac cavity, as the first part of the stomach is called. In this latter cavity there are glands which secrete the gastric juice, and which fluid is necessary to digestion. We should here also note a particular provision in the upper orifice of the gizzard, namely, the overlapping of a part of the muscle, which produces an obliquity in the passage, and holds the contents of the stomach confined during the strong action of grinding. It was indeed at one time supposed that such a mechanical operation of the stomach as we have described in the gizzard, fitted the food to supply the nourishment of the body; but, we repeat, that it has no further operation than that of comminuting the hard food, and preparing it for the action of this animal fluid, the gastric juice, which digests; and digestion is the first process of assimilation.

It may be interesting to the reader to know that the lower orifice of the gizzard, where it opens into the first intestine (*duodenum*), is differently guarded in different families of birds. In birds which have abundance of food, the gizzard has no valve to retard its escape; so that a greater part of the grains or seeds on which they feed passes off undigested; a fact which we touched upon elsewhere. Were birds of prey furnished with the same grinding apparatus which is suited for birds that feed upon grain, our argument would be overturned. But in them the gizzard is very weak; the cuticular lining of the stomach very thin; and the gastric glands, which pour out the digesting fluid, very large. In the hawk and kite we find no such macerating crop as in the domestic fowl.

Our author states that one class of birds cannot digest grains; the other cannot digest flesh. This, however, taken literally, does not accord with the experiments of Mr. Hunter, since he brought the carnivorous birds to live on grains, and the granivorous fowls to live on meat. But the necessity of accomplishing this change by very slow degrees leaves the substance of our author's argument sustained.

It is presumable that animal and vegetable matter are, in their ultimate elements, nearly the same; and, therefore, the last action of assimilation of the food is probably similar in all creatures. The variety of organization or structure in the stomach will be found to depend

on the proportion of nutritious matter in the mass that is swallowed. A vegetable feeder requires, from the poverty of its food, to be continually digesting; and happily its food is in abundance around it. The carnivorous animal gorges its food, after long and irregular intervals; its prey is precarious; but then that food is richer in nutritious matter, and requiring to undergo only the last process of assimilation. The variety and complication in the structure of the digestive organs depending on the nature of the food, is not only exhibited in quadrupeds and birds, but in fishes and in insects. Insects that suck blood have a simple canal: the grasshopper and white ant, vegetable feeders, have a complicated canal. Just for the same reason the intestines of the lion are short and wide, and those of the goat long and complicated.

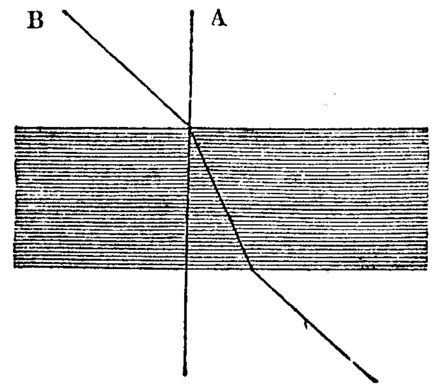
XVI.

ON THE RAYS OF LIGHT, THEIR REFRACTION AND REFLECTION.

THE nature of light has ever been a subject of controversy. It was Newton's explanation that luminous objects give out particles of inconceivable minuteness, and moving with extreme velocity. "What mere assertion," says Sir John Herschel, "will make any man believe that, in one second of time, in one beat of the pendulum of the clock, a ray of light travels over 192,000 miles; and would therefore perform the tour of the world in less time than a swift runner would make one stride?" In short, there is nothing like it but the influence of attraction; which is so instantaneous as to admit of no calculation of time at all.

A different theory from that of Newton was suggested by Huyghens, who supposed a highly-elastic fluid to fill all space, and which, when moved, produced the effects ascribed to light. Instead of minute particles diverging from the luminous body, he substituted waves or vibrations, propagated through this elastic ether. The late Dr. Young, and some continental philosophers more recently, took up this hypothesis and supported it by ingenious experiments. But notwithstanding that it is the favourite theory of the day, difficulties appear still to encumber it. The theory of undulations implies the advance and recoil of the elastic medium, and that gives the idea of retardation. The supposition of light being the effect of the motion of an ether, does not fall in with our conceptions of the manner in which it enters into the composition of bodies, or influences chemical combinations, or affects the living powers of animals and

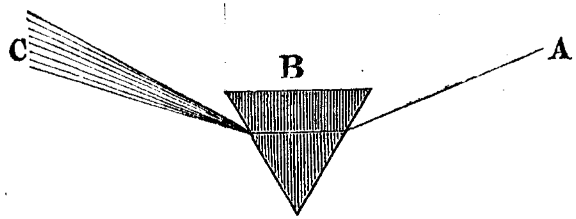
vegetables. The merits of the two theories, however, need not be discussed here. It will be sufficient for our purpose to represent a beam of light by a line drawn with the pen, and to enter on the explanation of a few of the laws which influence it in passing through transparent media.



When the ray of light, as A, passes perpendicularly from a rarer into a denser medium, as from air into water, it suffers no change in its direction; but when it passes obliquely, as B, it takes a new direction towards the perpendicular, making a sudden angle, as if broken, —and this is refraction. Two circumstances, therefore, influence the ray of light;—the angle at which it falls, and the density of the body into which it passes. When the ray B passes from the denser medium into the rarer, it is again refracted, but away from the perpendicular, and takes its original course, provided the surface at which it goes out is parallel to the surface at which it entered.

When a ray strikes upon a body that is not transparent, or only imperfectly so, it is in part reflected, that is, struck off again, bent back, or reflected, and enters the eye, conveying to us the impression of the form and colour of that object.

But the expression which we have used requires explanation; for how is it that the reflected rays should convey the idea of colour?

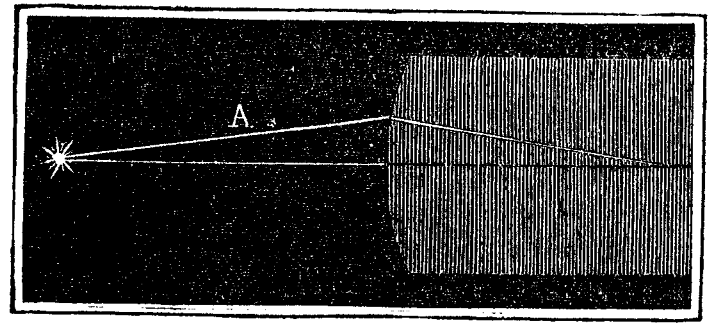


The prism is a piece of glass so formed that the rays must fall obliquely on one or both of the surfaces, and suffer refraction. Thus the ray A striking into the prism B is refracted; but all its parts are not equally refracted, and as the light consists of parts differing in colours, and which are differently refracted, it is divided or dissected into several colours C, called the prismatic colours. The spectrum, as it is termed, thus formed, consists of seven colours; that which is least refracted being red, and in succession orange, yellow, green, blue, indigo, and violet. If these rays be re-compounded by passing through a convex lens, which, owing to the obliquity with which they fall, draws them to a point, the focus of the light will be again colourless. Some modern philosophers have reduced these prismatic colours of Newton to three primary colours, red, yellow, and blue; contriving, by the super-position of these, to produce the seven tints; while others have, on considerations not easy to be disproved, held that there is not any definite number of colours, but a gradation of tints from the extreme red to the extreme violet.

We may now understand the reason of the colour of objects. When light strikes upon a body, even upon the most transparent, part penetrates, part is reflected, and some part is lost. A dye is a disposition given to the surface of cloth to repel some of the rays of light more than the others; and the colour will be according to the ray, or the combination of rays, thus cast back and sent into the eye.

And here it is natural to reflect on the variety and

beauty everywhere bestowed through this property of the beam of light. What a dulness would have pervaded the surface of the earth if there had been only a white light! The beauties of the garden and of the landscape would have been lost to us. How is the beauty of the latter enhanced by the almost infinite variety of colour, yet still within that range which is agreeable and soothing to the eye, as well as consonant to our feelings! The human countenance, too, although capable of exciting our warmest sympathies by form and motion alone, has that beauty perfected by colour, varying under the influence of emotion.



It remains, in order that we may apply these facts to the explanation of the structure of the eye, to show how the rays proceeding from a body and falling upon a convex glass suffer refraction. The ray that strikes upon the centre, being perpendicular to the glass, passes on undeviatingly. But each ray as it strikes a point removed from the centre, must impinge with more obliquity, in consequence of the curved surface; and as the refraction of all the rays will be in proportion to the obliquity of their incidence, they will converge towards the central direct ray. Thus A, as it passes through the glass, suffers refraction towards the perpendicular line, in proportion as it deviated from it, on passing out of the air into the glass. These few simple statements may suffice for understanding the comparison which we are now to make between the eye and optical instruments.

XVII.

THE EYE COMPARED WITH OPTICAL INSTRUMENTS.

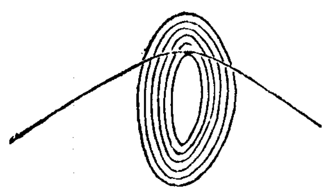
We have elsewhere expressed our surprise that the structure of an animal body should so seldom be taken as a model. In the history of inventions, it appears quite extraordinary that the telescope and the microscope should be modern, when, as it should seem, the fine transparent convexity of the eye might have given rise to imitation, as soon as man learned to give shape to natural or artificial glass. It reminds us of the observation of Locke, in speaking of a discovery, that it proved the world to be of no great antiquity. Yet we must estimate the invention of the telescope and microscope as by far the most important in their consequences of either ancient or modern discoveries. The first opens to us an unlimited expanse, not only of new worlds, but systems of worlds, and new laws evinced in the forces which propel and attract these; since in the heavenly bodies we find no material contact, nor pressure, nor impulse, nor transfer of power—nor effect of heat, nor expansion of gases—nothing, in short, which can be illustrated by mechanism. By the microscope, we contemplate the minute structure of animals and things but for its aid invisible: the balance of the cohesive and repulsive forces as they order the changes in the material of the world, and in that of our own frames. Yet these instruments are not in contrast with the eye: but through the comparison of them we discover the wonderful adaptations of that organ; of which it has long ago been said, that it can at one time extend our contemplations to the heavenly bodies and their revolutions, and at another limit its exercise to things at hand, to the sym-

pathies and affections of our nature visible in the countenance.

If we put aside the consideration of the living properties of the organ, as the extraordinary variety and degrees of sensibility in the nerve of vision, and confine ourselves to points easily comprehended, as, for example, the mechanism of the eye, and the laws of optics as applicable to the humours, we shall find enough to admire.

When we look upon the optician's lens, however perfect its polish may be, we can see its convex surface: that is to say, the rays of light which strike upon that surface do not all penetrate it, but are in part reflected to our eye, which is the occasion of our seeing it. We do not see the surface of the cornea of the human eye. Here, then, is an obvious superiority, since it implies that all the rays of light which strike the cornea enter it and are refracted, and none are returned to our eye. If we take the optician's lens between our fingers and hold it under water, we can no longer see it, however transparent the water. The reason of this is, that the rays of light are reflected when entering from a rare medium into a denser, more abundantly in proportion to the difference of the density. When the ray of light has penetrated the water, it also penetrates the glass, because there is not that difference of density between the water and the glass which there is between the atmosphere and the glass. From this we may estimate the importance of the surface of the cornea being moistened by the tears; for however thinly the water may be spread over the surface of the eye, it is sufficient to make those rays that would otherwise be reflected penetrate the cornea.

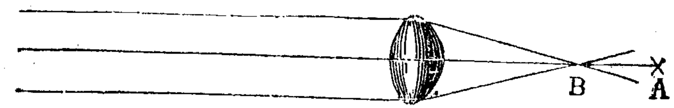
The whole humours of the eye are constituted with a regard to this law. There is nowhere an abrupt transition from a rare to a dense humour. The ray is transmitted from the cornea into the aqueous humour, and through that humour into the lens or crystalline humour. Were this latter humour uniform and of the density of its central part throughout, the ray would be in part reflected back from its surface. But it is not uniform, like a mass of glass: it consists of concentric layers increasing in density from the surface to the centre. If we first look at the entire lens, and then take off its concentric layers, we shall see the surface of the internal nucleus more distinctly than the exterior and natural surface. The reason is obvious: the nucleus is so much more dense than the atmosphere, that the reflection of the rays from it is more abundant. We now comprehend how finely it is provided that the crystalline lens should be surrounded with the *liquor Morgagni*, a fluid which is but in a slight degree more dense than the aqueous humour. The exterior surface of the lens itself is only a little more dense than the surrounding fluid, and each successive layer, from the surface to the centre, is of gradually increasing density: so that if we were to describe the course of the ray, it would not, as we see in the ordinary diagrams, pass like a straight line of the pen, but in a curved line,



showing the gradual manner in which the ray is refracted through successive transparent layers. As it enters in the anterior half of its passage, it encounters media of increasing density: but as it passes out behind, it is transmitted through media diminishing in density. The ray is nowhere opposed by that sudden increase of density which gives a disposition to reflection; and it passes through the vitreous humour still refracted, the density of that humour having a just correspondence with the posterior surface of the lens. In the atmosphere there is a similar arrangement for receiving the light proceeding from the sun or stars: for as the density of the air diminishes as the height above the earth increases, the surface of our atmosphere, from its rarity, must almost resemble free space; consequently the light falling into it will penetrate more abundantly than if the air were compressed as it is near the earth, and were of uniform density. We

thus see the obvious superiority in the structure of the eye to any thing that can be composed of glass, which is of uniform density throughout, and must therefore present a succession of surfaces where rare and dense media are abruptly opposed to the rays transmitted.

We may observe another happy result from the peculiar structure of the lens. A magnifying glass is never true; an aberration of the rays takes place in the pencil of light, as the rays are drawn to a focus. The rays which penetrate near the centre are projected so as to be drawn to their focus beyond those rays which pierce through nearer the edge. The rays penetrating the centre of this double convex glass will project the image to A, whilst those penetrating nearer the circumference, and consequently falling more obliquely, will form a focus nearer the lens at B. But in the crystalline humour of the eye, which corresponds with the optician's lens, the exterior layer having less density, and therefore a diminished property of refracting the ray, the image is carried farther off to A; and by this means it is ordered that, wherever the ray penetrates, it shall be drawn to an accurate focus.



Some modern philosophers have asserted that the eye is not perfectly achromatic in every adjustment. The term implies the property of the instrument to represent an image divested of the prismatic colours; those false colours which attend the refraction of the rays of light. If the statement be correct, it is nothing against our argument; nor have those inquirers advanced it with any such view.* We know that in all the ordinary exercises of the eye the image is perfect, having neither penumbra nor prismatic colours. This property of the eye results

* Professor Blair (*Edinburgh Transactions*, iii.) expressly derives an argument in favour of design from this statement of his opinion, and his objection to Boscovich.

from the different media through which the rays are transmitted, and the gradual transmission which we have just mentioned. Dollond's achromatic glasses, a great improvement upon the telescope, were made on this principle. He composed the object-glass of the telescope of crown-glass and flint-glass; so that while, by the combined effect of their convexities, they drew the rays to a focus, the dispersive power of the one was counteracted by that of the other.

Let us endeavour to explain this. A, a beam of light, being composed of the different coloured rays, passes through the prism B. (See Fig. p. 92.) Instead of passing onward in a straight line, it is refracted to C in distinct and, consequently, coloured rays. Whilst the whole of them are bent or refracted at an angle from the dotted line, they are also diverging from one another. Their deviation from the straight line is their *refraction;* their diverging from each other is their *dispersion.* These properties being distinct, it is conceivable that glass of a different chemical composition may affect the one to a greater degree than the other, and, therefore, that a lens may be composed of different kinds of glass (crown-glass and flint-glass, for example), so that the convergence of the rays into a focus may be obtained without the dispersion of the rays, and the consequent production of false colours round the image. This is what Dollond nearly accomplished, and upon these principles. That the effect of this very artificial arrangement is attained in the eye is a remarkable proof of the perfection of its adaptation to the properties of light.

The last circumstance which we may mention in continuing the comparison, is the drawing out of the tube in the telescope to accommodate the foci of the glasses to the distance of the object. It is sufficient to say that the eye possesses this property of accommodation. That we do not understand how the operation is performed, only strengthens the argument in favour of the perfection of the eye; since the power exists, and is exercised with an ease which hardly permits us to be sensible of it.

XVIII.

OF THE MEANS BY WHICH THE EYE IS PROTECTED.

When an astronomer, in the darkness of night, and shaded from the light of his chamber, moves his telescope from star to star, his eye is accommodated to faint impressions; that is, the sensibility of the retina is then accumulated, so that when he directs his instrument to the brighter objects his sensation is painful. And if, at another time, he should be observing the sun, without having guarded the eye by smoking the glasses, or by some other means diminishing their transparency, the stroke upon the retina will not only be painful, but may prove destructive to its fine texture, and occasion a defect of vision which will continue through life. If the apparatus in the tympanum of the ear be destroyed, and the defect supplied by an ear-trumpet, the person will be startled by those who speak into this trumpet; for if they are not in the habit of pitching their voices distinctly and softly, the sound will jar painfully upon his ear. By these considerations we are prepared to contemplate that beautiful provision by which the natural eye is protected against the sudden intrusion of light, or the too intense illumination of the object upon which it is directed.

The iris is a curtain, or septum, which stretches across the aqueous humour, and is anterior to the crystalline lens; it is perforated in the centre, and that perforation is the pupil—the black central spot which we see when we look into the eye—black, for the reason which we have assigned, that the rays piercing there are not returned, and the absence of rays is blackness. But the rays strike the anterior part of the iris itself round the perforation, and they are partially at least reflected, giving the colour to the eye—grey, or blue, or hazel.

Perhaps the diagram (vol. ii., p. 22) will explain the structure of the iris and pupil, and show the mode in which the pencil of rays is enlarged or diminished, and the intensity of the image in the eye thus made greater or less in proportion to the illumination.

The iris, then, we understand to be a muscular septum or partition, with two sets of fibres; a straight set converging to that margin of the iris which forms the pupil, and a circular set running round the exterior margin of the iris. At page 189 of vol. ii. we have given a representation of the iris of the lion. The pupil or open space is oval in this animal; B B are the straight fibres converging to the exterior margin of the iris; and C C are the circular fibres of the margin. These two sets of fibres act against each other, and in a moderate light the pupil is moderately expanded; but when the light is obscure, the circular fibres relax, and the straight fibres act; the iris is then diminished in diameter, and the pupil enlarged. The contrary takes place when too intense a light strikes into the eye.

This guardian action of the iris is more rapid than words, and as quick as thought; and it is to be remarked that this apparatus is animated by nerves which go back to the sensorium; so that the impression must be received in the sensorium before the iris can be directed in its motions.

Such, then, is the apparatus by which the nerve of vision is guarded; and as marking its necessity, let us remember that the retina is susceptible, in an extraordinary degree, of various impressions of light, that it will be sensible to an object illuminated as one, and as thirty thousand. It is obvious that either we must have groped in the dark during the evening or moonlight, or have been quite dazzled and overpowered by the brightness of the sun, had not this fine mechanical apparatus of the iris been adapted and assigned for the protection of the nerve.

But the nerve is protected in another way, or rather, we should say, the force of the impression is regulated. We have seen that the colours of objects are owing to the rays of light being reflected from them; that on a surface perfectly black the rays sink in and are lost, and we recognise the object only by its outline being contrasted with surrounding coloured bodies, not by the light reflected from itself. When the eye of an animal is destined for the bright light of day, a black pigment is behind the nerve, and the nerve itself being transparent, the ray is transmitted and lost. But if it be required that the eye shall be suited to the habits of an animal that prowls by night, then there is combined with the large eye and the very dilatable pupil, calculated to receive a great pencil of rays, a property of reflection in the *tapetum* or carpet; that is, the surface at the bottom of the eye on which the nerve is expanded. Instead of the black and absorbing pigment, there is a secretion furnished by that surface, which, like a dye, throws off or reflects the light, or reflects it back like the silver on the back of a mirror. This gives a second impulse to the nerve, and has the effect of doubling the force of the impression.

Let us now see how an organ of the extreme transparency and delicacy of the eye is guarded from injuries of another kind.

And, first, we may observe the combination of the living properties with the motion and mechanism of the eye-ball; how the extreme delicacy of the surfaces of the eye has adapted to it the fine sensibility seated in the eye-lids and roots of the eye-lashes. The pain excited by the smallest particle that floats in the atmosphere would be the source of constant suffering, were there not connected with and animated by the same sensibility an apparatus, mechanical and hydraulic, for the obvious purpose of ridding the delicate surface of the eye of all foreign matter.

Can there be anything more interesting than to find the whole of this apparatus under the guidance of a property different from that of consciousness and volition?

I have seen many instances of persons deprived of the sensibility of the surfaces of the eye from the affection of one nerve alone, without the loss of vision, or of the motions of the eye-lids, or of the flow of tears; but it has been impossible in such persons to preserve the organ, by assuring them of the necessity of these motions, either through the direct action of the eye-lids, or by the aid of their fingers. The eye's surfaces, being deprived of sensation, are no longer regularly moistened; soot and dust rest upon them; and, although they are insensible, they inflame; the transparent cornea becomes opaque, and the eye is lost. This is the consequence neither of the want of sensibility in the retina, nor of the capacity of motion in the eye-ball and eye-lids being lost, nor of failure of the spring of water that runs continually over the eye: it results simply from a loss of that relation in the sensibilities suited to the materials and influences around us, and the protecting motions which they excite. It at once answers the querist who asks, why we suffer pain? We reply to him by another question. How are we to hear or see, or how enjoy the sense from impressions so delicate as those of sound and light; or enjoying these, by instruments so exquisitely framed, how are these instruments to be protected from the ruder shocks to which they must be exposed? These considerations lead to the conclusion that if he object to one part of the system, he objects to the whole of that by which we hold our present existence.

The motions of the eye and eye-lids, which are directed by this sensibility, must be performed with extreme rapidity. To rinse anything in water, or to rid it of dust by shaking it in the wind, the action must be quick; and such a motion is possessed by the eye of the fish, although the eye-lids and lachrymal apparatus are in them unnecessary.

If we are giving proofs of design, we can have none more obvious than that suggested in the Preliminary Discourse, in the eye of the mud crab, an animal which, like the eel, seeks its food in mud and turbid water. Emerging from such a bed, its eye is covered with slime, and would be useless: but to provide against this inconvenience there is a little brush near the eye, to which the prominent horny eye can be raised, and against which it is wiped, with an action as intelligible as that of a man wiping his spectacles. The cray-fish, too, which burrows in the banks of rivers, has the same provision, although the structure is less perfect.

I have assumed that the action of the eye of fishes is rapid. I must confess that I have not seen this, but we are entitled to conclude that they possess the motion, as fishes have other muscles besides those necessary to direct the eye; muscles which, by the oblique direction of their fibres, are calculated to give extraordinary rapidity of motion, and resemble that apparatus which gives the rapid instinctive motions to our own eye.

The first time that we observe any remarkable phenomena, they excite more emotion, and we describe them with more interest. I shall therefore extract here a portion of a paper given to the Royal Society on the nerves of the eye, which it was necessary to preface by observations on the actions of the muscles, a subject which I conceived had not been fully understood.

XIX.

MOTIONS OF THE EYE-BALL AND EYE-LIDS.

WE shall consider the muscles of the eye, first, as necessary to its preservation; secondly, as necessary to it as the organ of sense. We do not reflect on those actions of our frame which are most admirable in themselves, which minister continually to our necessities, and perfect the exercise of our organs, until we are deprived of them: like unnatural children, unconscious or unmindful of indulgence, we feel only the loss of benefits. "With much compassion," says the religious philosopher, "as well as astonishment at the goodness of our loving Creator, have I considered the sad state of a certain gentleman who, as to the rest, was in pretty good health, but only wanted the use of those two little muscles that serve to lift up the eye-lids, and so had almost lost the use of his sight, being forced, as long as this defect lasted, to shove up his eye-lids with his own hands." I have often thought of this saying when I have seen a patient in all respects in health, but without the power of raising the eye-lids.

There is a motion of the eye-ball, which, from its rapidity, has escaped observation. In the instant that the eye-lids are closed, the eye-ball makes a movement which raises the cornea under the upper eye-lid.

If we fix one eye upon an object, and close the other eye with the finger, so as to feel the convexity of the cornea through the eye-lid, we shall perceive when we shut the eye that is open, that the cornea of the other eye is instantly elevated; and that it thus rises and falls in sympathy with the eye that is closed and opened. This change of the position of the eye-ball takes place during the most rapid winking motions of the eye-lids.

When a dog was deprived of the power of closing the eye-lids of one eye by cutting across the nerve of the eye-lids, the eye did not cease to turn up when he was threatened, and when he winked with the eye-lids of the other side.

Nearly the same thing I observed in a girl whose eye-lids were attached to the surrounding skin, owing to a burn; for the fore part of the eye-ball being completely uncovered, when she would have winked, instead of the eye-lids descending, the eye-balls were turned up, and the cornea was moistened by coming in contact with the mouths of the lachrymal ducts.

The purpose of this rapid insensible motion of the eye-ball will be understood by observing the form of the eye-lids and the place of the lachrymal gland. The margins of the eye-lids are flat, and when they meet, they touch only at their outer edges, so that when closed there is a gutter left between them and the cornea. If the eye-ball were to remain without motion, the margins of the eye-lids would meet in such a manner on the surface of the cornea, that a certain portion would be left untouched, and the eye would have no power of clearing off what obscured the vision, at that principal part of the lucid cornea which is in the very axis of the eye; and if the tears flowed they would be left accumulated on the centre of the cornea, and winking, instead of clearing the eye, would suffuse it. To avoid these effects, and to sweep and clear the surface of the cornea, at the same time that the eye-lids are closed, the eye-ball revolves, and the cornea is rapidly elevated under the eye-lid.

Another effect of this motion of the eye-ball is to procure the discharge from the lachrymal ducts; for by the simultaneous ascent of the cornea, and descent of the upper eye-lid, the membrane on which the ducts open is stretched, and then the tears flow unimpeded.

By this simultaneous motion, also, the descent of the eye-lid and the ascent of the cornea, the rapidity with which the eye escapes from injury, is increased. Even creatures which have imperfect eye-lids, as fishes, by possessing this rapid revolving motion of the eye, avoid injury and clear off impurities.

I may observe, in passing, that there is a provision for the protection of the eye, in the manner in which the eye-lids close, which has not been noticed. While the upper eye-lid falls, the lower eye-lid is moved towards the nose. This is a part of that curious provision for collecting offensive particles towards the inner corner of the eye. If the edges of the eye-lids be marked with black spots, it will be seen that when the eye-lids are opened and closed, the spot on the upper eye-lid descends and rises perpendicularly, while the spot on the lower eye-lid will play horizontally like a shuttle.

To comprehend these actions of the muscles of the eye, we must remember that the caruncle and membrane called *semilunaris*, seated in the inner corner of the eye, are for ridding the eye of extraneous matter, and are, in fact, for the same purpose as that apparatus which is more perfect in beasts and birds. The tears are imbibed by the *puncta* or orifices, which may be seen in the inner corner of the eye; and a tube, formed on the principle of a siphon, carries them into the nose: whilst the dust, washed to this corner, is thrown out by the apparatus which we have described.

The course of our inquiry makes some notice of these parts necessary.

In quadrupeds there is a gland for secreting a glutinous and adhesive fluid, seated on the side of the orbit next the nose: it is quite distinct from the lachrymal gland; it is squeezed by an apparatus of muscles, and the fluid exudes upon the surface of the third eye-lid. This third eye-lid is a very peculiar part of the apparatus of protection. It is a thin cartilage, the posterior part of which is attached to an elastic body. This body is lodged in a division or depression of the orbit on the side towards the nose. When the eye is excited, the eye-ball is made to press on the elastic body against the side of the orbit and force it out of its recess or socket; the consequence of which is the protrusion of the cartilaginous third eye-lid, or *haw*,

as it is termed in the horse. By this mechanism the third eye-lid is made to sweep rapidly over the surface of the cornea, and, by means of the glutinous fluid with which its surface is bedewed, it attaches to itself and clears away offensive particles.

In birds, the eye is an exquisitely fine organ, and still more curiously, we might be tempted to say artificially, protected. The third eye-lid is more perfect than that of quadrupeds: it is membranous and broad, and is drawn over the surface of the eye by means of two muscles attached to the back part of the eye-ball, one of which acts by a long round tendon, that makes a course of nearly three parts of the circumference of the ball.* The lachrymal gland is small, and seated low, but the mucous gland is of great size, and placed in a cavity deep and large, and on the inside of the orbit. As the third eye-lid is moved by an apparatus which cannot squeeze the mucous gland at the same time that the eye-lid is moved, as in quadrupeds, the oblique muscles are particularly provided to draw the eye-ball against the gland, and to force out the mucus on the surface of the third eye-lid. It flows very copiously; and this is probably the reason of the smallness of the proper lachrymal gland which lies on the opposite side of the orbit.

We already see two objects attained through the motion of these parts: the moistening of the eye with the clear fluid of the lachrymal gland, and the extraction or protrusion of offensive particles.

There is another part of this subject no less curious: the different conditions of the eye during the waking and sleeping state. If we approach a person in disturbed sleep when the eye-lids are a little apart, we shall not see the pupil or the dark part of the eye, as we should were he awake, for the cornea is turned upwards under the upper eye-lid. If a person be fainting, as insensibility comes over him the eyes cease to have speculation; they want direction, and are vacant, and presently the white part of the eye is disclosed by the revolving of the eye-ball up-

* See p. 33, vol. ii.

wards. Look to a blind beggar; those white balls are not turned up in the fervour of entreaty; it is the natural state of the eye-balls, which are totally blind, and from the exercise of which the individual has withdrawn his attention. So it is on the approach of death; for, although the eye-lids be open, the pupils are in part hid, being turned up with a seeming agony, which however is the mark of increasing insensibility. These motions of the eye for the protection of the organ do not interfere with vision; they are performed unconsciously, and so rapidly that the impression of the object on the retina has not time to vanish in the interval. The motions of the eye-ball for directing the eye to objects are strictly voluntary, and are always connected with the exercise of the sense of vision.

It will now be admitted that the variety of the motions of the eye requires the complication of muscles which we find in the orbit, and unless the various offices and different conditions of the eye be considered, it will be in vain to attempt an accurate classification of the muscles or nerves of the orbit.

XX.

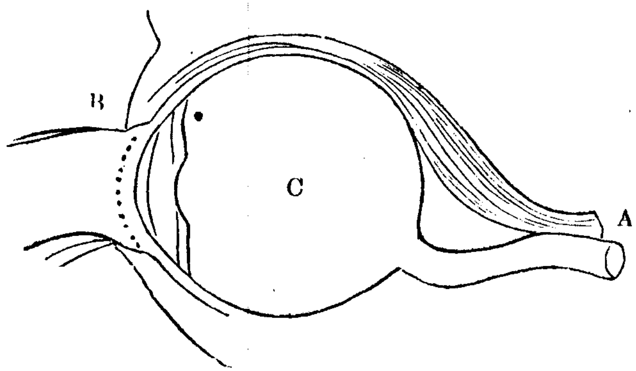
MUSCLES OF THE EYE-LIDS.

Even in the action of the muscles of the eye-lids, although the most exposed and familiar parts of any, there is something new still to be observed. The eye-ball is held betwixt the *levator palpebræ*, the muscle which raises the eye-lid, and the *orbicularis*, that which depresses it; the one as it elevates the eye-lid tending to protrude the eye-ball, the other to compress and restrain it.

In paralysis of the *orbicularis*, the muscle which closes the eye, the eye-ball is protruded; it starts more forward than is natural; the eye-lid is loose and flabby, and can be lifted like a bit of common skin.

It is from this protrusion of the eye-ball that the upper eye-lid is raised, and the lower eye-lid depressed, by one muscle. Anatomists have sought for a depressor of the inferior eye-lid, seeing that it is depressed; but such a muscle has no existence, and is quite unnecessary. The *levator palpebræ superioris* opens wide the eye-lids, depressing the lower eye-lid at the same time that it elevates the upper one. If we put the finger upon the lower eye-lid so as to feel the eye-ball when the eye is shut, and then open the eye, we shall perceive that, during this action, the eye-ball is pushed forwards. Now the lower eye-lid is so adapted as to slip off the convex surface of the ball in this action, and thus to be depressed, while the upper eye-lid is elevated.

The origin of the levator being at A, and the insertion into the cartilage of the upper eye-lid at B, the effect of the action of the muscle must be the protrusion of the eye-ball C to the dotted line. By the elevation of the upper eye-lid, the eye starts forward a little, and the lower



eye-lid therefore slips off the lower segment of the eye-ball.

It is curious to observe how the eye-ball retreats in its condition of repose, and is protruded when about to be exercised in vision. High excitement, as in terror, when the eye-balls are largely unclosed, is attended with an increase of the sphere of vision produced by the protrusion of the eye-balls; a change remarkable both in the ferocious and timid animals, especially in the latter.

Such were the views of the motions of the eye-ball and eye-lids, introductory to a paper on the muscles of the eye—itself introductory to observations on the nerves of the orbit. The discussion relating to these is too strictly and minutely anatomical for our present purpose. It will be sufficient if I state the deduction,—that by the eight muscles around the eye, and the six nerves, whose extremities reach them, two sets of motions are provided; the first for the voluntary direction of the eye-ball in strict sympathy with vision; the other in connexion with the mechanical and hydraulic apparatus for the protection of the organ. When we enjoy the sense of vision, the voluntary muscles are excited; but, in sleep, another class preponderates, over which we have no voluntary power; and this is the condition of rest as well as of safety to the organ.

XXI.

REVIEW OF THE USES OF THE PARTS IN THE EAR.

We find late physiological writers acknowledging their ignorance of the functions of the particular structures in this organ; and we cannot therefore conceal that there is a difficulty in assigning the uses of the parts. Nevertheless, we shall now endeavour to explain our conceptions of this matter; and, at all events, there is enough to prove the main argument of design and of the fine adaptation of this organ to the laws by which sound is propagated.

The outward ear of man and animals is so obviously provided for collecting sound that there can be no cavil here. It is extended and moveable in those animals which hear acutely, and in some, as the bat, it is double, consisting of one expanded membrane within the other. And this brings to mind an assertion, that the membrane of the tympanum is affected by the vibrations of the side of the auditory tube more than by the direct impulse of the atmosphere against it; for if there be one conical expanded external ear within another, it is obvious that there must be a larger surface to receive vibrations and communicate them to the tube and membrane of the tympanum.

It suffices with some to say that the undulation of sound is received upon the membrane of the tympanum, and by it is communicated to the atmosphere within. But how is the infinite variety of sounds, all, in fact, that we hear, communicated simultaneously through the same membrane? In the first place, the membrane is not simple, nor is it muscular, but contains within it cords or fibres which run from its outer margin, converging towards the malleus. It is now that we look with great interest upon the experiments of Chladni and others on metallic plates. He strews dust upon one of these plates, and then brings out a note by drawing the bow of the violin upon the edge; when the sand, or powder, or dust, will arrange itself in regular figures. These figures are remarkable for their symmetry, dividing the circumference of the plate into equal parts, from six to forty; or the sand divides itself into circles having the same centre with the plate, and the diametrical and circular lines combine to produce an astonishing variety in the configuration of the particles. Here, then, we have a proof that, instead of there being a general undulation or vibration of the whole membrane of the tympanum, it may be subdivided, a motion taking place in its minute parts, and these having many nodes or centres which remain motionless; in short, we perceive a capability of motion in the membrane corresponding with the variety of sounds which we know to be propagated through it. And if we should imagine that the general surface of the membrane was unsuitable for so great a variety of compound motions, the chords visible upon its interior surface may be considered sufficient to allow it to correspond with every possible variety of note. (See fig., vol. ii., p. 41.)

How satisfactory soever the ingenious experiments in acoustics and with musical instruments may be, there is a difficulty which has not been met in assigning the offices to some of the parts in the ear. The chain of bones in the tympanum undoubtedly communicates the sounds from the membrane of the tympanum to the proper seat of the sense, the labyrinth; and nothing is more easy than to conceive that the membrane of the tympanum, receiving an impulse, like a sail flapping by the wind, should communicate the same to the malleus and in succession to the other bones. But the difficulty arises from considering that it is not a mechanical impulse which is communicated, but a motion of sound. When philosophers teach us the nature of sound by throwing a pebble into a still pond of water and making us observe the concentric undulations: or by striking a cord and observing the motions which accompany the sound, and showing the harmonic

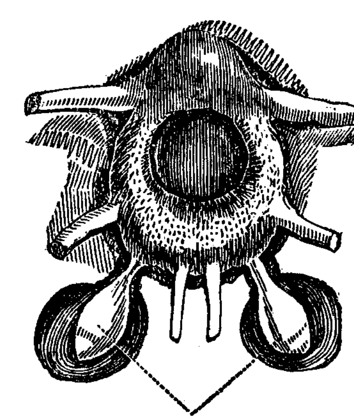
subdivisions, we seem to have overcome all the difficulties of the science. But we encounter new difficulties when we are forced to conclude that all the combinations of sound in an orchestra, for example, are transmitted through a chain of bones, some of which are not greater in diameter than a horse-hair. We are reminded that the undulations visible to the eye or felt by the finger are not the motions of sound, although they accompany them, and that they must be of a nature much more minute and delicate. There is no instance of one organ of sense conveying the knowledge of a quality of matter for the perception of which another organ is provided. Still, perhaps, these microscopic observations may assist our invention. When a powerful lens is applied to a metallic cord sounding, and we distinguish the brilliant particles on its surface, those particles have not the motions merely to and fro which are caused by the division and subdivision of the elastic cord: those brilliant particles dance in figures infinitely varied, combined of circles and angles which it is perhaps impossible to describe and reduce to any system. Such facts aid us in comprehending how different motions of sound may be communicated at the same moment.

It is ascertained that if a metallic rod be placed in contact with a sounding-board to which the sounds of many instruments playing in concert are communicated, and if that rod be extended to a great length, or if it be carried through a partition, so that we are out of ear-shot of the instruments, and if the rod communicate at its further end with another sounding-board, the motions of that board will be given out to the atmosphere, and we shall hear the concert, that is, the combined sounds of the instruments, although necessarily faint. Here, then, the music must have been conveyed along the rod; and we have another proof that sound cannot consist of those coarser movements ascertained by the other senses, but of something so infinitely more minute that the particles in the rod may convey distinct vibrations simultaneously. These considerations certainly countenance our belief, that however fine the chain of bones may be which, passing through the tympanum, communicates between the external and internal ear, it is yet capable of a variety of motions corresponding with the sounds, of which the ear is susceptible.

What, then, is the meaning of this very obvious mechanical structure in the chain of bones in these little levers and their attached muscles? (See fig. p. 39, vol. ii.) Are not the three muscles attached to the bone that is fixed to the membrane calculated to affect the tension of the membrane? If we take the illustration in the text, we must remember that the military drum is not so simple as it has been represented. The chords or braces, which pass outside the drum obliquely, are tightened by pushing down the knots of buff leather, and this not only stretches the parchment head of the drum, but tightens the snares or cords which run over the parchment of the reverse of the drum. In the military drum, it is the blow on the parchment that gives the loud and sudden sound; while the chords alter and prolong the sound. The three muscles which are attached to the malleus and through it to the membrane of the tympanum we must suppose may either brace or throw loose the membrane and its cords; as the drum is braced or muffled: and in this way the small muscles of the tympanum may have a resemblance in function to the fibres of the iris; they may guard the nerve of hearing as the latter does the nerve of vision. We had occasion to observe, that when a person is deaf from the disorder of this apparatus, and when he substitutes the ear-trumpet, he may hear; for the ear-trumpet, by its expanded mouth, collects the undulations of sound and concentrates them; but there is this imperfection, that the ear wants its power of adjustment; and the person is accordingly often timid in the use of his instrument with those who are not accustomed to speak to him, the sound of some voices being painfully harsh. Further, we may not hear a sound when called upon to listen to it, and yet when the particular sound is described, we do hear it; now it remains to be determined whether this be a power of adjustment in the ear, or owing to the effect of association in the mind.

It is supposed by some that there are two tracts by which sound is communicated to the labyrinth; that it passes both through the chain of bones and through the air in the tympanum. With regard to the last mode, I can conceive no cavity less suited to convey sounds. Instead of having a definite form like the tube of the ear, by which the vibrations might be received and directed inwards, the tympanum opens into the cells of the temporal bone, and presents the most irregular surface possible, and such as would inevitably break and destroy any regular sound. The extension of cavity of the tympanum is calculated to increase the elasticity of the air in the tympanum, but most certainly not to collect or to strengthen the sound.

With regard to the labyrinth, comparative anatomy lends us considerable assistance. Were vibrations of sound being communicated to the brain the cause of hearing, the brain itself would be the organ and no special nerve necessary. The brain in some animals, being placed in a cavity, and surrounded with fluid, is subjected necessarily to vibration. But we perceive that in addition an appropriate nerve and distinct organ are bestowed. There is here, in the cuttle-fish, very little apparatus in this organ,



[This figure represents the form of the brain in the cuttle-fish, as an example of its very simple structure: A the simple auditory apparatus.]

and it proves that the essential part of the ear is the nerve suceptible of sound, and not the exterior apparatus. Some sixty years ago, learned men in Italy wished to ascertain whether the lobster had the organ of hearing or not. The celebrated Professor Scarpa, then a young man, undertook to decide that matter; not by looking for the exterior organ, but by examining the brain and the nerves which go out from it. Finding that there was a nerve which stood in the relation of an acoustic nerve, he traced it onward, and found it terminating in a little sac containing fluid, and open to the influence of the atmosphere by a small membrane which crossed the mouth of it. This was the just and philosophical mode of proceeding. There being, in fact, nothing in the brain itself, with respect to its exposure to tremours or motion, different from the auditory nerve, if that nerve had had merely to convey a vibration to the brain, it would have been superfluous, as the brain itself would have vibrated. Hence we perceive that an endowment of a nerve which shall be susceptible of the sense of sound is necessary, and consequently it is the primary and essential part of the organization. How the motions of sound shall reach it is another question.

Let us now carry along with us the fact that solids and fluids are much better vehicles of sound than the atmosphere; that it is the rarity and elasticity of the atmosphere which makes all that exterior apparatus which we have been considering necessary. Accordingly, an exterior ear is not wanted in the fish. If a man dive under water and carry a stone in each hand and strike the stones together, he is sensible of a stunning sound, and indeed of an impression on the whole surface of his body. In short, although it was once doubted whether water were capable of propagating sound, a hundred instances can now be brought forward to prove that it can receive or propagate every degree of sound and tone. Again, when we find that the solid parts of the head convey sounds, we perceive that in the fish there is no occasion even for an external opening, far less an external ear. An apparatus of a totally different kind is bestowed.

Within a little sac of fluid a bone or concretion is suspended, which, being more solid than the surrounding fluid, receives the vibration, and moves, necessarily producing waves or motion in the surrounding fluid, and consequently an agitation of the extremities of the nerve exposed to the fluid. A very simple but curious experiment of Professor Camper illustrates the effect of this structure: A bladder containing a marble and full of water being held in the hand, the slightest motion of the hand was attended with a vibration communicated from the water to the hand: the effect of the motion of the marble upon the surrounding water.

With respect to the semicircular canals above described, I am at a loss to understand what is meant by some authors saying that their use is not known. These canals consist of an elastic membrane full of fluid, with a nerve suspended upon the septum of one extremity: are they not then admirably suited to receive the impulses which are conveyed through the bones of the head? That they are so, is clear from their being found in the heads of fishes, where there is no access of vibration to the nerve except through the bone. But we are affected by the same when our head is on the pillow and we are awakened by people moving in the house: the alarm is through the solid bones of the head. And when the Indian puts his ear to the ground to hear a distant tread, he is substituting the communication through the solids and the bones of the head for the atmospheric impulses.

Again, let us recur to the proposition that sound is propagated to the internal ear in two ways: through the chain of bones and fenestra ovalis into the vestibule, and also through the air of the tympanum, and by the fenestra rotunda into the cochlea. There appear strong objections to this doctrine. It declares the chain of bones and their appended muscles and beautiful articulations to be altogether useless; for if the sound can be communicated through the air of the tympanum, what is the meaning of this complex apparatus? And if the bones of the ear communicate better, what is the use of the vibration coming by any other course? Let us understand, then, that the whole exterior apparatus—that is to say, the parts exterior to the labyrinth—are necessary only to perfect hearing, and that when they are all gone by disease, those essential parts of the organ which we see suffice in the lower animals, continue to receive sounds.

The apparatus of bones and muscles connected with the membrane of the tympanum (see vol. ii., p. 39) is of more consequence than physiologists allow. It is essential to perfect hearing, even when the sound is conveyed through the solid bones. If we hold a watch between the teeth, the sound is propagated through the solid parts; but let us compress and close the outer tube of one of the ears, and the sound will be increased on that side. If a person, being deaf in one ear, put his watch close to that ear, he will not hear the ticking; but, if at the same time he presses on the tube of the other ear and closes it, he will then hear the ticking on that side. It appears that in this experiment, the sound propagated through the bones is not given directly to the nerve, but to the membrane and bones of the tympanum, and through them back upon the nerve. The air in the outer tube of the ear, being pent up by the pressure of the fingers and compressed, receives the vibration, reverberates on the membrane of the tympanum, and puts the apparatus within the tympanum into play.

Drawing a fair inference from the demonstration, it would appear that the impulses upon the membrane of the tympanum are communicated to the membrane of the fenestra ovalis, and that the opening called the fenestra rotunda, closed by a similar membrane, is for the purpose not of receiving impulse from without but of yielding to that impulse from within. For example, if we suppose a bottle of water full to the lip, and a bladder drawn over it so that not a bubble of air is contained, although that water must be admitted to be compressible, an impulse upon the bladder would produce no such effect as would follow were there a hole covered with a bladder upon the side or bottom of the bottle; for then each impulse upon the top would be attended with a yielding of the bladder below, and a consequent agitation in all the intermediate

fluid. Thus, it appears to us that the use of the fenestra rotunda and its membrane is to give play to the membrane of the fenestra ovalis, and that without this provision, although there might be a general impulse communicated to the fluid in the labyrinth, like that communicated through the bones generally, there could be no wave or undulation. If the shutting of the Eustachian tube, D, (page 37, vol. ii.), so confines the *air* in the large cavity of the tympanum as to render us deaf, what would be the consequence of the labyrinth (which contains *water*) being shut in on every side? The play, then, of the bones of the tympanum, and of the membrane of the fenestra ovalis and of the fenestra rotunda, is not only required to produce an undulation in the fluid within the labyrinth, but that undulation must take the particular course through the scala of the cochlea, descending into it by the scala vestibuli and ascending by the scala tympani. (See F, vol. ii., page 37.) In this view it becomes interesting to consider the distribution of the nerve in the cochlea, since this internal part of the organ is so obviously connected with the finer exterior apparatus. We have learned that the nerve passes into the modiolus and extends to the edge of the lamina spiralis, so that the sonorous undulations continued through these passages must affect the nerve on two surfaces; and whether we consider the cochlea to be like the bending of the spiral turns of a wind instrument, or the fibres of the lamina spiralis to be like a succession of chords diminishing regularly in length, we can at least imagine that at one time the whole portion of the nerve may be brushed and agitated, and that at another it may be partially affected.

In short, the concavities of the central cavity of the labyrinth, the vestibule, may produce an eddying of the fluid, so that the motion shall be concentrated to a point, on which point there is seated a portion of the nerve; or the undulation may pass round the semicircular canals and affect the septum of each ampulla; or by being propagated through the cochlea it may touch fibres of the lamina spiralis of different lengths. All we mean to affirm is, that there is so great an extent and variety in the distribution of the acoustic nerve, and also in the canals and cavities, as fairly to give us reason for believing them to be the sources of that extensive scale, and of all the changes and combinations of sound which we enjoy through this sense.

XXII.

OF THE CIRCULATION.

LIFE in the animal body is attended with a never-ceasing change in the whole framework. Not merely is there a current of blood running in a circle, but all the things that enter into the composition of the animal body, solids as well as fluids, are under an influence that keeps them in incessant change. This, indeed, is the object or end of the circulation: for the blood contains in a fluid state what had composed the solid framework. We might say that the solid matter was resolved or melted, but that it is a vital action which thus reduces the texture to the condition of a fluid. At the same time that the blood concontains what has been the material of the body, it consists also of new matter, the product of digestion and assimilation, and which is destined to take the place of the material that has been removed. The circulating blood is thus made the agent by which the revolution of the solid animal frame as well as of the fluids is accomplished.

We learn by this, that there is nothing permanent in the living body. We see, and perhaps without much surprise, that a part cut heals, that a part excavated or taken away is soon replaced, and in some of the lower animals that members cut off are actually reproduced: all this we see, but it requires fine experiment and accurate reasoning to enforce the conclusion that the animal body is always growing, always forming; and that this incessant revolution in the material of the frame is the grand distinction between the living structures of the animal body and machinery. In the former there is a principle of renovation incessantly at work, so that the action or exercise is attended with no wear and tear, but, on the contrary, the greater the activity the more perfect the structure, and what we term the healing process, or the reproduction of parts, is the continuance of an action which has had no interval.

It being absolutely proved that there is nothing permanent in the body, we leave the reader to consider the question, which forces itself upon him, " What, then, is it that gives identity? How comes the peculiarity of form and constitution and complexion to remain—or how does the memory serve us—when the material has been many times removed?" But we have rather to consider the grand operation by which these changes are wrought —the circulation.

Modern chemists have estimated that 5208 grains of charcoal are thrown off from the blood in twenty-four hours, and this uniting with 13,392 grains of oxygen in the atmosphere that is breathed, constitutes, with a due proportion of caloric, the carbonic acid gas which is discharged from the lungs. Other secretions are also disposing of the material of the body; and although these be necessary to health, it is the function of respiration which is the most directly necessary to life, and which is guarded by pain and anxiety experienced the moment that interruption is begun.

We may already comprehend how the blood flows in a great circle, taking up the material of the body by the absorbents and veins of the body, and throwing it off by the lungs: and how blood returning from the lungs, purified by exposure to the atmosphere, comes back to the heart to complete its circle. We readily conceive also how this pure blood is necessary to all the vital operations, to the nourishment and growth of the body; but it is not so easy to comprehend the manner in which the force of the circulation ever keeps pace with the condition of the body: active during the exercise of the body, reduced and equable during repose; or how the body generally will have the circulation moderate in degree, whilst an individual part being excited and in action shall be accommodated with an activity of circulation exactly

apportioned to the necessity for it. It is not possible, on mere hydraulic principles, to explain how the blood shall descend to the toes or ascend to the head by one impulse, and yet with a force exactly proportioned to the distance and elevation of the member. Nothing is more admirable than the manner in which the heart, as the great engine in the centre, has its irritability and power of action united in close relation to the condition of the body. If the pulse is to be felt by the physician, the person must recline, for if he stand up, on hydraulic principles a greater force is required to move the upright column of blood, and the heart beats more rapidly; and this, especially, is more remarkable, if the person be sickly and weak. For the same reason no physician feels the pulse when his patient is anxious or perturbed, or at least he must calculate on the pulse being accelerated. These and many other examples might be brought to show that the circulation alters in correspondence with the position of the body, and with its exercise; and that it alters with the emotions of the mind, as well as with the changes in the position and movement of the frame. We learn from this that the heart, through its sensibilities, is the regulator of the circulating system, and that it is for this purpose that it has such extensive sympathies. These remarks we premise as reminding the reader that there are more things to be admired in the contemplation of the living animal frame, than can be brought under the head of the mechanism of the circulating organs, or the adaptation of the tubes to the known principles of hydraulics. It is, however, to these that we must now beg his attention.

XXIII.

OF THE VEINS.

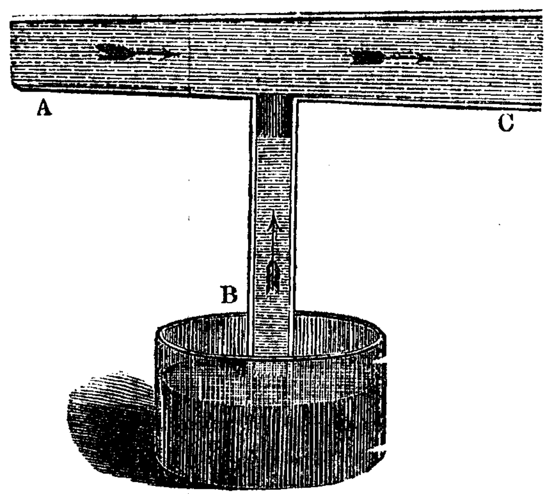
Our author has taken up the notion, which indeed is conveyed in anatomical books, that the veins are irregular in their form and course. We hold this to be a dangerous admission: first, because it leads to the supposition that there is a certain imperfection, and as it were negligence, in the structure of the frame; and secondly, because it induces the inquirer to be satisfied with a very superficial survey. The veins are considered as mere conduit-pipes, to carry back the blood from all parts of the body to the heart. But they are much more; they are reservoirs. Where could that large proportion of blood which is necessary, be deposited with more safety to life than in those recesses or interstices left by the bones and muscles of the body? But whilst this object is secured, another more important one is attained by the turning and twisting of the veins into the crevices and unoccupied spaces: for they become thus liable to be pressed by the action of the muscles; and so it comes about that the blood is permitted to move on slowly in these recesses whilst we lie inactive, but when we are aroused into action, it is pressed onward, the dimensions of the reservoirs are diminished, and the blood is accumulated upon the more active heart, and is ready to answer the demands of the system which that very activity requires. The sensations at the heart exciting the respiration, the chest is expanded, and the veins enlarged; and by the alternate suction and compression upon those great veins, the heart is liberally supplied. By this arrangement, then, there is ever a correspondence preserved between the activity of the body and the rapidity

of the circulation. For this is the sequence of actions—1. We rise into activity; the blood, which was slowly circulating, is pressed forward to the heart: 2. The heart is distended and excited: 3. The sympathy or bond of union between the heart and lungs makes a call upon the respiratory action; and the decarbonization of the blood takes place more rapidly: 4. The return of arterial blood from the lungs to the heart is accelerated, and the heart regulates the action of the arteries: 5. The increased arterial action supports the exercise of the muscular frame; and, thus, there is a circle of relations established arising out of that very seeming irregularity of the veins; their position and general condition ensure an acceleration of circulation corresponding with the activity of the muscular system.

True it is, that, in comparing the branching of the veins with the arteries, there seems to be, as anatomists have taken pains to show, an appearance of clumsiness and irregularity in the former compared with the latter; but they have not inquired whether there was a reason for this variety—whether the distinction in the manner of a small tube joining a larger, accords with the direction of the fluid in these tubes or not—and yet this is a question very naturally suggested, if we have a firm conviction that in the natural body nothing is formed imperfectly, or by chance. Accordingly, it does appear that, in the distribution of water-pipes, it is very necessary to attend to the angle at which a small pipe joins a larger. If a pipe be fixed into another contrary to the direction of the stream, the discharge into that lateral branch from the larger tube will not only be much smaller than what we might estimate by the diameter of the tubes it should be, but in certain circumstances it will discharge nothing at all; nay, the water will be drawn from the lesser tube into the greater.

Bernouilli found that when a small tube, B, was inserted into the side of a horizontal conical tube, A, in which the water was flowing towards the wider end, C, not only did no water escape through the smaller tube, but water in a vessel, at a considerable distance below, was drawn up through the lesser tube into the greater.

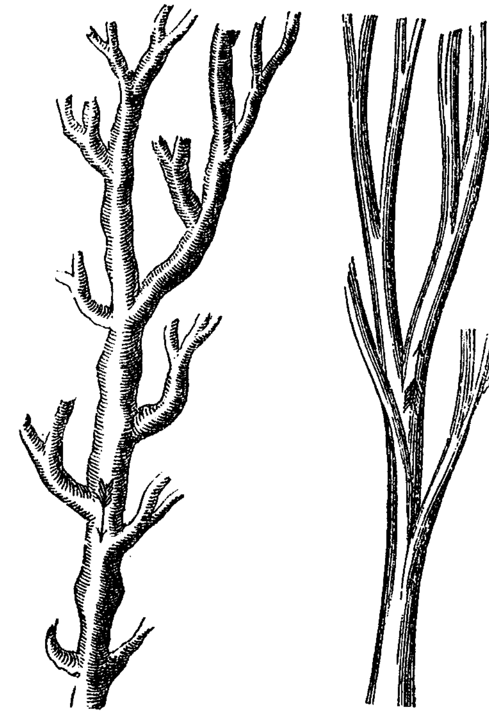
With these facts before us, we turn with interest to the curves of the arteries and veins, seeing that the contained fluids flow in the one from the trunk to the branch, in the other in an opposite direction from the smaller to the greater vessel.



And now, if, instead of taking the artery as the important vessel, and the vein as less so—and therefore negligently contrived, we consider both of them to be important and perfect—we ought to expect that their course and curves should differ.

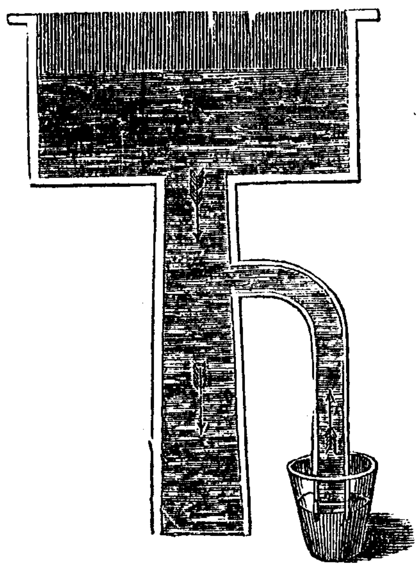
In the artery, where the blood is passing from the heart towards the extremities—that is, from trunk to branch—the branches slightly diverge from the direction of the stream in the trunk; whilst the branch of the vein, where the blood is passing from the lesser into the larger vessel, enters abruptly and at right angles. From this it appears, that if we could imagine such a malformation as that the offices of these vessels were changed, congestion would immediately take place, and the circulation could not be carried on.

It appears, further, that if the veins were rigid, or placed in circumstances where their sides remained apart when wounded, instead of blood escaping, air might be



drawn into them through the expansion of the chest in breathing—and this is a most important circumstance; for when such an accident takes place, death follows instantaneously. When a reservoir is emptied by a perpendicular tube, into which a smaller tube is inserted, the water descending by the larger tube, instead of escaping by the lesser, will draw the water up through that lesser tube so as to empty the glass in which its lower end is immersed. By this we see that there may be points on the sides of tubes conveying fluid, in which the pressure may be negative; and we are made aware that the arrangement in question, instead of being a negligent or irregular joining of the branch to the trunk, is, on the contrary, a provision for the lesser tube entering at a proper angle into the side of the greater one.

If two tubes join to form a larger tube, and a hole be bored at the angle of their union, and if the water flow from the lesser tubes into the greater tube, no water will escape by the hole: in other words, there is a point of negative pressure. Now it is remarkable that the vessels which are called absorbents enter into the venous system at the angle of union of the great veins; that is, at the point of negative pressure.



XXIV.

ON THE ARTERIES.

There is perhaps no finer proof of the adaptation of the apparatus of circulation to the principles of hydraulics than the fact of the increasing diameters of the arteries as they recede from the heart. Mr. John Hunter took great pains to prove this: and he did demonstrate that when a great artery divided into two branches, the united areas of the branches were greater than the area of the trunk; that when the branches subdivided, the united areas of the subdivisions were greater than the areas of the vessels from which they were derived, and so on to the extreme vessels. Reflecting on this, it is interesting to find that the engineer in laying down pipes comes practically to the conclusion, that a pipe dividing into two branches, whose united areas are exactly equal to the area of that from which they proceed, will not deliver the same quantity of water that would have flowed through the greater tube. He discovers that he must take into account the attraction and friction of the fluid upon the solid, and that the smaller the calibre of the tube, the surface of attraction or friction will be proportionably the greater. Does not this fact coming out in practice prove to us why the united areas of the smaller branches of the artery are larger than that of the trunk from which they are derived? If any further explanation be necessary it is this—that the water flowing in a tube runs more rapidly in the centre than at the sides—or, in other words, that there is a certain attraction or friction at the sides. We see this in standing by a flowing river; the friction of the water against the bottom and the sides retards the stream, whilst the velocity of the current is greatest in the middle. As the water in the river is delayed at the bottom and sides, so is the fluid nearest the sides of the tube retarded by the friction between the fluid and the solid. Thus we see a remarkable coincidence between the increasing diameters of the circulating vessels, and of tubes laid down upon accurate hydraulic principles.

From the diameter of the arteries being larger as they recede from the heart, two advantages are obtained: first, that the blood is driven on with greater ease; and secondly, that the extreme arteries become in some measure like the veins, reservoirs of blood. A man of middling stature has thirty-three pounds of blood in his circulating vessels; and did the vessels not enlarge as they receded from the heart, there would be no place for the deposit of this great quantity of blood.

We may venture upon some further illustrations.—A stream of water, unconfined, will take a very different form if falling by its own gravity from what it will do if forced in any other direction, by a *vis à tergo*. When water is poured out of a vessel it acquires velocity as it descends; the column is largest above and drawn fine below, because it is increasing in velocity, and the stream that has a greater velocity must be smaller in diameter: but continuing to descend, the stream acquires such a degree of velocity that the atmosphere offers resistance, and then it again spreads out. But a column of water sent upwards as a *jet d'eau*, instead of contracting as it ascends, enlarges. The fluid is retarded as it mounts; and the stream being still propelled from below, it is forced between the filaments of the column above and disperses them, enlarging the column as it ascends and giving it a conical form. Hence it follows that if water is to be discharged from a reservoir along a horizontal tube, it will flow more rapidly if the tube be a cone, with its lesser end inserted into the reservoir; for the weight of the water in the reservoir still being a *vis à tergo*, and the stream from behind forcing itself between the filaments of the column and so dispersing them, it is clear that the increasing diameter of the tube will correspond with the natural enlargement of the column of water, and give it an unimpeded exit. Here, then, we have another explanation of the increasing diameter of the arteries to receive the blood propelled by the heart.

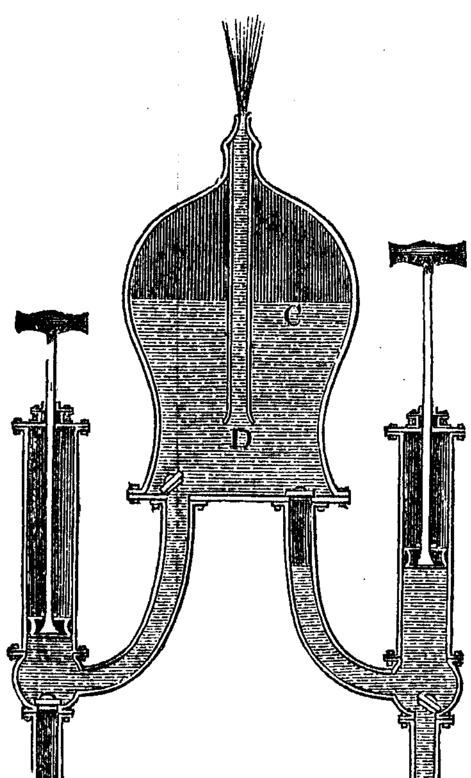
In laying pipes for a *jet d'eau*, the ascent of the water will be diminished by any sudden angle in the tube; and the *ajutage* must rise from the horizontal pipe with a gentle sweep, or the jet will not reach so high as it ought to do, from calculating the height of the water in the reservoir. This circumstance explains the parabolic curve which the great artery takes in going off from the heart; it explains also why the branches of this great artery go off at different angles, and why near the heart the branch goes off at a greater angle from the direction of the stream.*

We have, perhaps, said enough to remove the notion that there is anything like irregularity in the course and distribution of the vessels of the living body. But there are some other laws of hydraulics which give interest to the structure and action of the circulating vessels. The elasticity of the coats of the artery is a subject of importance in surgical pathology, and has very properly been deeply considered. This power has not, however, met with sufficient attention as one of the forces propelling the blood.

The law of inertia is easily comprehended as it regards solids. Every thing about us proves that it is more difficult to move a body at rest, than to accelerate it when it has been put in motion. The same law holds of a column of water in a pipe: it is easier to keep it in motion than to put it in motion from a state of rest. From this it follows that, in propelling water through a pipe by a forcing-pump, as the impulse is given at intervals, and as the whole column is at rest after each stroke of the piston, much of the force must be lost. Now if the heart contracted and propelled the blood into the artery, and there was then an interval of rest, during which the blood was stationary, the next pulsation of the heart

* This refers more especially to the intercostal arteries.

would be in part at least exhausted in bringing the blood from a state of rest into a state of motion. This will be best understood by following the successive contrivances which the engineer has employed, in raising water, to keep the column in motion uninterruptedly, and therefore to use his power in accelerating the stream, not in bringing it from a state of rest into a state of motion. The first idea was to have two forcing pipes instead of one, so that one stroke should succeed another without interval. But it was soon discovered that there was a difficulty in adjusting exactly the two forces; and so it was found that three forcing-pumps were better than two, as more effectually providing against any interruption to the motion of the stream; the second filling up the interval between the impulse of the first and third. This



multiplication of the parts of the engine shows the desire of the engineer to avoid interruption in the stream. But it does not so well illustrate our proper subject as the next invention, which was to employ an elastic power; and the engineer contrived it thus:—A portion of air is confined in a reservoir; the pipes of two forcing-pumps are carried into the reservoir, and they fill it half full of water, C; the mouth of the pipe, D, which is to convey away the water, reaches into the water in the reservoir. As the water rises, the air is compressed: so that, although the pumps act alternately, the elasticity of the contained air acts uninterruptedly in pressing on the surface of the water, and raising it by the tube, D, in an equable stream. The elasticity of the contained air fills up the interval between the actions of the pumps, and admits of no interruption to the force with which the water is propelled upwards.

Surely these are sufficient indications of the necessity of three powers acting in propelling the blood from the heart. The first is a sudden and powerful action of the ventricle: the second is a contraction of the artery, somewhat similar, excited by its distention: the third, though a property independent of life, is a power permitting no interval or alternation; it is the elasticity of the coats of the artery: and these three powers, duly adjusted, keep up a continued stream in the blood-vessels. It is true that when an artery is wounded, the blood flows in pulses; but that proceeds from the regular acceleration of a jet which yet has no actual interruption. Were not this continued flow of the blood provided, there would be a loss of power, at each pulsation of the heart, in carrying the blood from a state of rest to a state of motion; and if we consider how many pulses there are in the twenty-four hours, 80,000, we may make some estimate of the loss of vital power that would accrue had there been a neglect of the law of inertia in the apparatus of circulation.

XXV.

MICROSCOPIC PHENOMENA IN THE ANIMAL BODY—MOLECULAR MOTIONS—CILIARY MOTIONS.

We have noted the judicious course pursued by Dr. Paley, in preferring the proofs of design drawn from the structures of our bodies, which secure our existence, or minister to our comforts or enjoyments; for in these there may well be perceived the object of the provisions, and the mode by which they are attained; and this supports us in a due estimate of ourselves,—seeing that there is so much care of us, and that our bodily and intellectual endowments have so many relations to the system of nature. By the aid of the telescope or microscope we are equally carried, as it were, out of ourselves, to view nature foreign to us. If, it has been justly observed, in contemplating the heavens with minds ill confirmed as to the intentions of Providence towards us, the study is far from being consolatory, the same may be said of the microscopic world. The discovery of the universal prevalence of life, of animals within animals, of the inhabitants of a drop of fluid as difficult to enumerate or arrange as those of the ocean, gives rise to thoughts which do not flatter our self-importance, more than the contemplation of the magnitude of the heavenly bodies, and the extent of space through which they range. It will, therefore, be tending to the object of this volume to show that with the microscope, that is, by observing the atoms of our frame which are invisible to the naked eye, we discover motions and actions, both of inorganic and animated particles, which tend to the preservation of life, and to the performance of the offices in the animal economy, fully as remarkable as the contractions of the heart, or the play of the lungs.

It will be necessary to the correct estimate of the facts which we have to mention, that we advert to a curious discovery of Mr. Brown, relative to the motions of inorganic molecules. This gentleman's celebrity is of a kind which may not readily be comprehended by some readers; for his retired and philosophical habits cause him to occupy a small space in society at home, in comparison with that reputation which extends wherever science is cultivated. He was directed to this subject by a motion visible in the pollen of plants, when under his microscope, which led him to further investigations; and he found that when inorganic as well as organic bodies were minutely divided, and floated in a drop of water, active motions were seen in the molecules. The motions of these particles are different from those of animated matter. The molecules are spherical, and between 1-20,000th and 1-30,000th of an inch in diameter. I have myself seen these, and nothing can be more surprising than their evolutions, like figures in a dance, apparently produced by the attraction and repulsion of the particles themselves. It might be supposed that the rapid evaporation from the surface of the drop would produce eddies within it, and that these molecules were carried by the circulation of the fluid; but the ingenious mode by which Mr. Brown prevented the evaporation of the watery particle, by surrounding it with oil, whilst the motions of the molecules continued, refutes this hypothesis, and inclines us the more to rejoice that the curious phenomenon was discovered, not accidentally, but by a philosopher.

Indeed, whilst looking upon these molecules, we are surprised by bodies, obviously animalcules, jostling them, and darting across the field of the microscope; and the natural reflection is, how much more minute must the constituent parts, or molecules, of these animalcules be! Their motions are not fortuitous, or owing to any polarization or influence external to them, as galvanism or magnetism: they have instincts and appetites, and are susceptible of excitement: their bodies are nourished by digestion, or imbibition: they have circulation, though it may be with a different apparatus from that of larger animals: their circulating fluids, their containing vessels, their apparatus for motion, imply that the ultimate molecules of their composition must be infinitely small, even in comparison with the minute particles which we are contemplating: and this we state, to do away with those speculations which men are prone to indulge in, when they suppose that they have at last attained a sight, in these active molecules, of the ultimate particles which constitute the frame-work of animals.*

Another class of facts drawn from the minute world is no less wonderful than the motion of these "active molecules:" we allude to certain vibratory motions, or, as they are termed, *ciliary* motions, on the mucous surfaces of animals. They are somewhat analogous to the actions of the rotatory apparatus of some of the infusoria. Both the respiration and the prehension of food in these animals are accomplished by an influence of their bodies, whereby a current is kept up in the surrounding fluid; a fresh stream by this means plays over the apparatus of their respiratory organs, whilst in some the minute particles of nutritious matter in the fluid are brought in contact with their prehensile organs.

The soft aquatic animals, called porifera, have many orifices on their surface, into which the surrounding fluid is drawn, and being then brought into a common sac, it is expelled through a larger central mouth.† We can conceive an action of these pores, by which the water may be sucked in and propelled; but the more curious action is that of the cilia, or filaments, with which their tentacula are covered. These cilia have a motion which produces a vortex in the fluid, and tends to convey the floating nourishment towards the mouth.‡

This well-attested fact leads us to comprehend the phenomenon which is the principal object of this note,

* Animalcules are visible in the microscope, so minute, that it is estimated that a million of them do not exceed in magnitude a grain of sand.

† Dr. Grant. ‡ Spallanzani.

and explains what is meant by "ciliary motions." It is here necessary to mention that what anatomists term the mucous membrane is the lining of all those tubes and cavities of the animal body which open outwardly, in contradistinction to the membranes which line the proper cavities of the body, and which are called serous membranes. It is of itself a circumstance tending to the support of the conclusions to which the whole arguments of this book point, that the fluids thrown out to lubricate these surfaces are various and appropriate to the nature of the cavity. The membrane which is continuous all around, and has no outlet, must be moistened by a fluid which is to be absorbed again; but the surface of the cavity which has an outlet is moistened by a fluid which is to be discharged as from an emunctory.

This brings us to the fact above referred to, which, if the observation has been correctly made, is by much the most extraordinary in the whole animal economy.* A portion of the mucous membrane of an animal recently killed is placed, with great nicety, under the field of the microscope, and in water: some fine particles, which will float in the water, are then added. What has been used with most advantage is the black pigment of the eye, which is easily diffused, and the particles of which are very minute. The experimenter is here cautioned to distinguish the molecular motions discovered by Mr. Brown, from those now to be described. A rapid vibratory motion is to be seen on the surface of the membrane, and these motions produce a current in the fluid in contact, which is made apparent by the floating of the minute particles of the pigment. The remarkable part of this phenomenon is the direction of these currents. The cilia, or small filaments projecting from the membrane, move in such a manner that the current is always directed towards the outlet of the cavity or tube; and thus it is conjectured that a new source and kind of action, independent of muscularity (that is, the irritability of the grosser muscular fibre), is provided for the gradual and

* First observed by Purkinje and Valentin.

regular ejection of the secretions from these tubes and cavities which enter deep into the animal structure. In this country these extraordinary endowments of the living surface are under the examination of one* who will prosecute the subject with philosophical precision, and the result of whose inquiries may be expected with an interest proportioned to the important nature of the facts.

* Dr. Sharpey, of Edinburgh.

XXVI.

ON LIFE.

When we survey the discoveries in the physical and abstract sciences, our wonder and admiration are excited by the grasp and various powers of the human mind; but we learn, also, that men acquire a habit of viewing objects, and of thinking, which trammels them, though possessed of the highest genius, when they change abruptly the subject of their studies.

The life of the body is a study new to science, and it has no natural alliance with any of the higher branches which occupy men of intellect; yet it requires a great reach of thought. Those who follow intricate mathematical deductions, calculate the return of comets, estimate the magnitude and attraction of the sun and planets, and even extend their investigations to the fixed stars, come to the subject as much under the influence of habit as the artisan who tries to accomplish by the dexterity of his hand, that for which a different manner of working has unfitted him. This may be a humiliating consideration, yet it must be acknowledged, or we shall never discover by what hypotheses we have hitherto been misled; nor can we be directed in a course of observation likely to advance the science of Life.

The chemist is in the habit of observing the laws of invisible powers, of elective attraction, of heat, and of electrical, or galvanic, or magnetic influences. He makes a step, from the observation of the mere ponderable and visible qualities of matter, to the study of laws which govern that which can neither be weighed nor confined; and we should imagine, therefore, that the process of his reasoning would prepare him for comprehending more easily the influence of life, as exhibited in the phenomena of the animal body. But it has been far otherwise. The chemist, when he commences the study of physiology, instead of pausing and considering that he is about to enter on a new region, where phenomena unexampled before are to be presented to him, or are to be seen through different media, and the forces estimated by different means, carries along with him habits of thinking which promise no improvement in this new field; and, coming encumbered with all his apparatus, proceeds to measure that property which gives sensibility, motion, and thought, by the instruments he has hitherto employed in marking the current and force of electricity; and regards the brain as no more than an electric pile discharging at intervals along the nerves the fluid successively developed. Such are the false analogies which satisfy ingenious minds, so that they cease from inquiry, and leave science stationary. The mathematical and mechanical physicians long retarded the true knowledge of physiology; and we are now nearly as much embarrassed by the fashion of the day, of applying, to investigate the laws of life, the mode of reasoning which has been successful in the chemical sciences. There are but two men who have enlightened us on the doctrine of the life of the body, Haller and Hunter—and this is, in other words, saying, that it is altogether a recent science.

It is necessary to premise thus much, that the reader may not feel disappointment, if he fail, at first, in attempting to comprehend the subject. What does he understand by life?—That intelligence, feeling, and motion, which he sees manifested in the animal body. If, in this understanding of the term, he hears that Mr. Hunter discovered that there was life in the blood, it is possible that he may receive the announcement with the same ridicule with which the world at first heard it. But let us see how the subject opened upon Mr. Hunter's mind. He was engaged in minute inquiries into the gradual development of the chicken in the egg. On breaking one egg it was found perfectly sweet; the next was in a high state of putrescence. What, then, was the difference of their condition? Now let us not confound this question with

what is termed organization. The chick at this time is concealed within a vesicle not larger than the head of a pin. It is the white and yolk of the egg that we are examining. Here is no heart, or vessels, or brain, or nerves, or anything of an animal body. The question of organization, then, is put quite aside. Nevertheless, Mr. Hunter conceived that the difference between the putrid and the sweet egg depended upon the influence of life, which in the latter counteracted the chemical affinities, and prevented the matter from falling into a putrescent state. If then, said he, the matter of the egg has that property of life to check and control the affinities which all matter divested of life is subject to, has it also the power of resisting the changes of temperature? And now, upon comparing the putrid and the living egg, he found that the latter resisted freezing; and he thus showed that the property which resists putrefaction is allied to the property of the animal body which preserves it in a uniform heat, though exposed to the changes of temperature in surrounding bodies. We see by this that a portion of matter in an egg, or in a seed, shall be endowed with a principle, which, however obscure, we perceive by its effects.

Thus, living matter is under the influence of laws totally distinct from those which govern dead matter. What shall we call this peculiar property? We have acquired a notion of life by witnessing the effects of many causes combined in the whole animal. Motion is in general the result of these; and so we associate life and motion. Mr. Hunter showed that each part of the body which possessed life exhibited it by different phenomena. He said truly, that when the muscle cut off from the animal recently killed still palpitated, it was by its property of life. Accordingly, when a portion of the blood was withdrawn, he observed that it exhibited properties totally different from dead matter: it was drawn a fluid; and this fluid presently coagulated. What, said his opponents, is there in this? Do we not see a fluid jellying, and becoming solid; and is this to be a proof of life? But Mr. Hunter demonstrated that the coagulation of the blood was not in any respect like the formation of a jelly; that heat neither accelerated nor prevented it; that it took place whether the fluid was left quiet or stirred; that nothing prevented the blood becoming solid but the contact and influence of the living vessels of the body. He showed, also, that the blood could be deprived of life or killed, and then it no longer coagulated. In short, he compared this property of coagulation in the blood to the contraction of the muscle; and, among other remarkable properties in the blood, he pointed out the coincidence, that when a man was killed by lightning, the muscle did not stiffen in death, that is, it did not contract, neither did the blood coagulate.

The next step of Mr. Hunter was to combat those who would represent the body as bearing a resemblance to machinery moved by a weight. In the machine, he said, the weight of the jack-stone is conveyed from one lever to another, and from one wheel to another; but what is there in this analogous to motions of the living body? Take away one of these wheels or levers, there is no property or power in it; take a part of the body, and it has life, not as a property common to all the body, like that of gravitation in dead matter, but each portion has that endowment of life which is demonstrable or evident by distinct phenomena: and then he adds, true it is, that there is the example of beautiful machinery in the animal body, but how much more admirable are the different endowments of life which, corresponding together, minister to the intellectual being! One part has the property of receiving impression, another has the property of transmitting it, though it could not receive it. The mind thus approached and influenced, gives out its mandate by cords totally distinct, and with different properties: these have no motion in themselves, but they arrange and control the moving organs of the body, which give locomotion and agency. The whole body, then, is a collection of parts, possessing different endowments of life, exhibiting, by different phenomena, the presence of that life; and these different endowments have a bearing to each other, or a systematic arrangement, by which the

communication is established between the mind and the external and material world.

Mr. Hunter illustrated the subject thus:—Death is apparent or real. A man dragged out of the water, and to appearance dead, is, notwithstanding, alive, according to the definition we have given. The living endowments of the individual parts are not exhausted. The sensibility may be yet roused; the nerves which convey the impression may yet so far retain their property, that other motor nerves may be influenced through them; the muscles may be once more concatenated, and drawn into a simultaneous action. That vibratory motion which we have just said may be witnessed in a muscle recently cut out of the body, may be so excited in a class of muscles, for example in the muscles of inspiration, that the apparently dead draws an inspiration. Here is the first of a series of vital motions which excites the others, and the heart beats, and the blood circulates, and the sensibilities are restored; and the mind, which was in the condition of one asleep, is roused into activity and volition, and all the common phenomena of life are resuscitated. Such is the series of phenomena which is presented in apparent death from suffocation; but, if the death has been from an injury of some vital part, the sensibilities and properties of action in the rest of the body, though resident for a time, have lost their relations, and there is a link wanting in that chain of vital actions which restores animation. Here, then, there can be no resuscitation; and the death of the individual parts of the body rapidly succeeds the apparent death of the body.

We perceive now that our original conception of life and the terms we use respecting it, in common parlance, are but ill adapted to this subject when philosophically considered. We early associate life and motion so intimately that the one stands for the other. If we then investigate by anatomy, we find a curious and minute mechanism in operation, an engine and tubes for circulation, and, in short, an internal motion of every particle of the frame; and the anatomist is also led into the error of associating in his mind life with motion and organization. But when we consider the subject more closely, and divest ourselves of habits and prejudices associated with words, we perceive that, without making any vain and even dangerous attempt at definition, life is first to be contemplated as the peculiarity distinguishing one of two classes into which all matter must be arranged: the one class, which embraces all living matter, is subject to a controlling influence which resists the chemical agents, and produces a series of revolutions, in an order and at periods prescribed; the other, dead matter, is subject to lapse and change under chemical agency and the common laws of matter.

Let us examine the body of a perfect or a complicated animal. We find each organ possessed of a different power. But there is as yet no conventional language adapted to our discourse on this subject, and that is the source of many mistakes; for when a man even like Mr. Hunter had his mind illuminated upon this science, how was he to frame his language, when every word that he used had already a meaning which had no reference to the discovery he had made—to the distinct qualities which he had ascertained to belong to the living parts?

The progress of science in the present day, although it does not bring us nearer to the comprehension of the nature of life, yet furnishes us with such analogies as enable us more easily to comprehend how this principle may be combined with the material of an animal body, and yet be perfectly distinct from it. The discoveries which have led to the atomic theory, and to that of the molecules of bodies being under a polaric influence, leave us with the impression that the minute particles of common matter (in contradistinction to living matter) are under an influence which may be bestowed or withdrawn: that as the index of the compass points to the north by no property of the metal itself, but through an influence given to it and existing around it, so do the most minute particles of bodies arrange themselves by some such superadded influence, and partake of polarization. If, then, according to the prevailing opinion of philosophers, everything we touch, or see, or taste, all matter, in short,

exhibits qualities arising from the arrangement of particles infinitely minute, and that arrangement resulting from an influence exterior to them, or superadded to them, does it not facilitate our conception of a power or property bestowed on what is termed living matter and yet essentially distinct? The difference between dead and living matter will then appear to be, that in the one instance the particles are permanently arranged and continue to exhibit their proper character, as we term it, until by ingenuity and practice some means are found to withdraw the arranging or uniting influence; and then the matter is chemically dissolved—resolves into its elements, and forms new combinations: whilst the life continues, not simply to arrange the particles, and to give them the order or organization of the animal body, but to whirl them in a series of revolutions, during all which the material is passive, the law being in the life. The order and succession of these changes and their duration do not result from the material of the frame, which is the same in all animals, but from that influence which we term life, and which is superadded to the material.

XXVII.

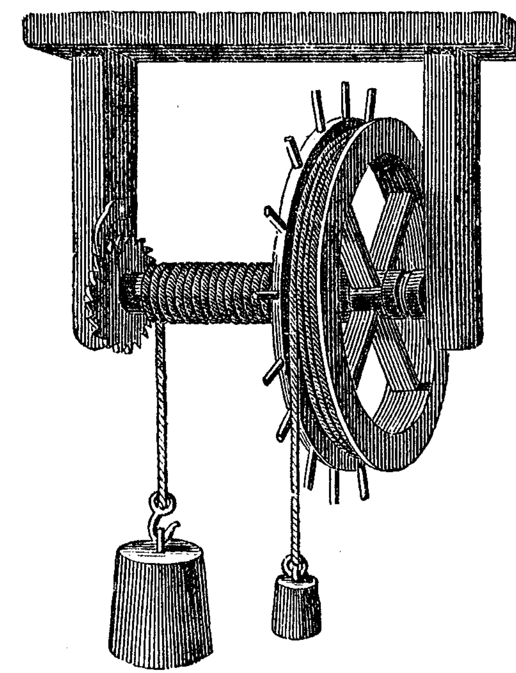
ILLUSTRATION OF THE WORKS OF A WATCH.

(See beginning of Chap. I.)

MANY, perhaps most, persons carry watches, without ever thinking how such pieces of mechanism become a measure of time. This incurious habit is hurtful, for it may prevail to the neglect of other objects. We must suppose such persons to be quite indifferent to the structure of their own frame, by which they move and have so many enjoyments. The subject forms a good lesson in mechanics for a youth. Let him look into his watch, and learn how the wheels act, and how all are regulated by the balance, to measure time.

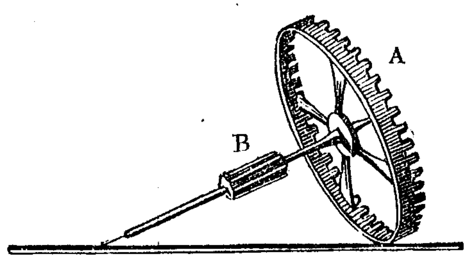
When men are advanced in science, they have sometimes little objection to see the particular subjects of their study involved in mystery. They are apt to deliver things in the form of a paradox. Thus they will affirm that the power of the hand, exerted through a machine, may raise a weight of many stones, and that one pound may weigh up one hundred. We are entitled to say, that the thing is impossible as the mechanist literally states it; that the props of the machine, the centre of the levers and the axles sustain by much the greater portion of the weight; and that the power of the hand is only given in addition to a weight which, though small, has, by the distribution of the force on the fixed points of the machinery, become balanced against the greater weight to be raised. This is obvious in the simplest form of a machine, *the wheel and axle*, when we see it at rest, and the lesser weight balancing the greater. In this figure the lesser weight and the greater weight are both sustained by the axle, and rest on the beams which sustain that axle.

Call the lesser body the *power*, and the greater body the *weight*; and the motions of these will be in proportion to their distance from the centre of the axle. Accordingly, we may measure the space through which they move, by pulling on the lesser weight, and seeing how much of the rope is uncoiled in one revolution of the wheel, and comparing that with the length of rope coiled up round the axle in the revolution, and consequently in the corresponding time.



A watch is an instrument where a set of wheels are made to revolve with a uniform velocity, and at a certain rate, so as to become the measure of time. When this motion is obtained, an index, or hand, is put on the axis of one of these wheels, and thus made to revolve on a dial, where the fractions of the revolution are marked. Two or more hands may be applied to different wheels, and these will indicate the subdivision of time in which the several wheels revolve in a minute, an hour, or in twelve hours.

In this figure, A is the wheel, and the notches, or rather the projecting points on it, the *teeth*.* B is the *pinion*, and the teeth on it are technically called the *leaves*. This is the wheel and pinion, and we perceive the resemblance to the wheel and axle. The teeth of the wheel move with a rapidity in proportion as the circumference of the wheel is distant from the axis or centre of motion.



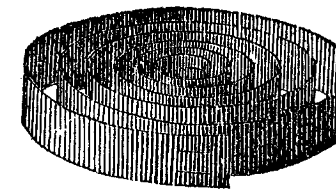
The wheel and pinion may be used either to accelerate motion, as when the power is applied to the pinion, or to diminish it, as when the power is applied to the teeth of the wheel, and conveyed through the leaves of the pinions to another wheel.

If there be forty teeth in a wheel, and this wheel plays into the pinion of another wheel having ten leaves, ten of the teeth of the first wheel will cause the second to complete its circle; and as there are forty teeth in the first wheel, the second will revolve four times for one of the first.

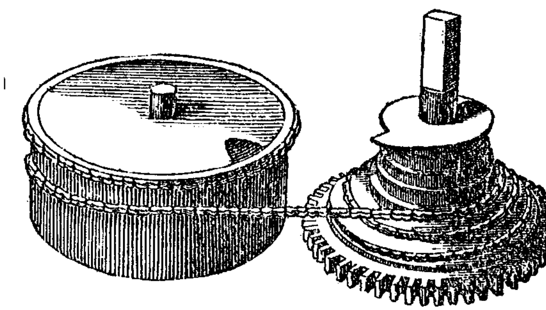
If things were reversed, and the motion commenced in the second wheel, so as to be communicated to the first, the mechanism would then have the effect of diminishing the motion to one quarter. In both these ways are the wheel and pinion employed in the watch.

The power moving the wheels of a watch is the

* The resemblance in these teeth to the jagged edge of a spur explains why certain wheels are called the "*spur-gear*." The engraver has here substituted, for my sketch, a crown wheel, that is, one where the teeth stand on the edge of a circlet, and parallel to the axis.



spring; it is here represented relaxed, as when the watch is run down.



On the left hand of this figure we have the *barrel*, a cylindrical box, in which the spring is coiled; and the extremity of the spring in the centre of the coil being fixed to an axle in the centre of the barrel, while the outer extremity is attached to the inner circumference of the barrel by a steel pin, the barrel must thus turn round as the spring uncoils.

The pyramidal body on the right is the *fusee*. In winding up the watch, the key is fixed on the pivot of this body, turns the fusee, and through the chain which joins it to the barrel the barrel is also turned round, and the spring within wound close up to its axle. When the key is removed, the spring acts, the barrel slowly revolves, and the chain, wound upon the barrel and drawing on the fusee, turns the fusee round. On the base of this body we observe the spur teeth of a wheel. This wheel is the source of all the movements in the watch.

We must not neglect to observe a pretty contrivance to make the mechanical power of the fusee correspond with the diminished power of the spring as it uncoils. The spring exerts the greatest force when it begins to uncoil itself, and this force is diminished as it relaxes. To correct this inequality the fusee is formed. It is an axle so contrived that, with the varying power, the motion shall be uniform, and for this purpose it has the form of a truncated cone with a spiral groove which receives the chain. When the spring is acting with the greatest intensity, the chain pulls on a part of the fusee, not much removed from the centre of its revolution, and therefore with a small leverage; but when the spring acts feebly, as the spiral groove becomes farther and farther removed from the axis of the fusee, the chain is uncoiled from it with a greater lever power.

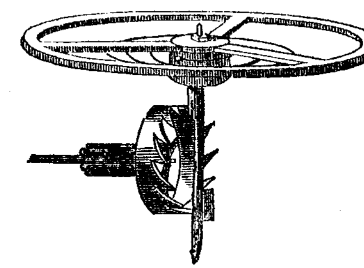
The great wheel on the base of the fusee checks into leaves of the pinion of the second or central wheel, and that moves, in succession, the third and fourth wheels. But before we estimate the effects of the respective wheels and pinions, we shall pass to the scapement, or balance.

The effect of the scapement is to preserve the moving power, or "sustaining force," uniform, to equalize the effect of the spring on the work; for although this is in part effected through the fusee, it is not done sufficiently.

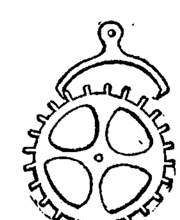
It is interesting and improving to observe, in the history of philosophy, how occurrences the most familiar become important when applied by genius to the arts. If a bell-rope hang free, and especially if a weight be appended to it, it will swing a long time. If we should chance to note the regularity and time of its motion, and so leave it, on returning, if it move at all, its motion from side to side (or its oscillation) will be performed in very nearly the same time as at first. Familiar and simple as this is, it is the *pendulum*, and the measure of time; and we can easily comprehend that if a rod, thus swung, be so appended to the work of a clock, as to receive a slight impulse, sufficient to keep it in motion, it will re-act on the clock; and if the motions of the wheels be nearly in accordance with the oscillation of

the pendulum, it will preserve the motion of the whole machinery correct.

Accordingly it is easier to make a clock than a watch; for in a watch some substitute for the pendulum must be found; and the substitute is a very delicate piece of work, called the *scapement*.



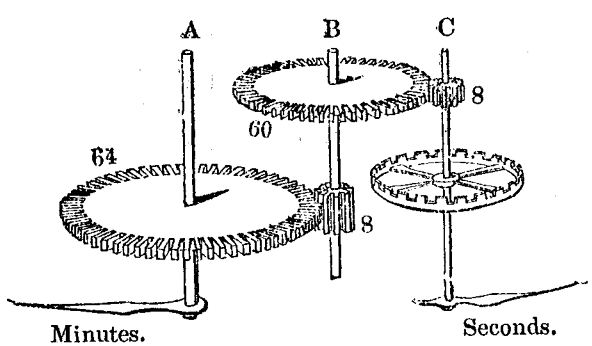
The upper wheel here is the balance-wheel, within which a fine hair spring is coiled. This spring is alternately pulled and let go by a motion communicated to the wheel; and the spring, by the regularity of its motions, answers the purpose of the pendulum. The notched wheel below is the scapement-wheel; two projecting *pallets* on different faces of the axle of the balance-wheel fall in succession between the teeth of the scapement-wheel; when one of these slips off the teeth, and the axle is set free, the spring recoils, and delivers the other pallet into the succeeding notch: and thus the regular motion of the spring, without stopping the revolution of the scapement, regulates the time in which the teeth are let loose, and by this means equalizes the motion of all the wheels.



Here is another form of the scapement-wheel. Call the upper part the *crutch*, the lower the *scapement-wheel*.

The sustaining force, which, in this instance, is the spring, operating through a succession of wheels, throws out the pallet of the crutch from the tooth of the scapement: in doing this the teeth act against a hair spring, which, by its recoil, places the pallet in the succeeding notch. By this contrivance the regular motion of the hair spring corrects the lesser deviation in the motion of the wheels which might otherwise arise from the imperfection of the workmanship. The balance-wheel and spring move with a quickness which permits the scapement-wheel to beat 18,000 times in an hour—the common rate of a watch that shows seconds.

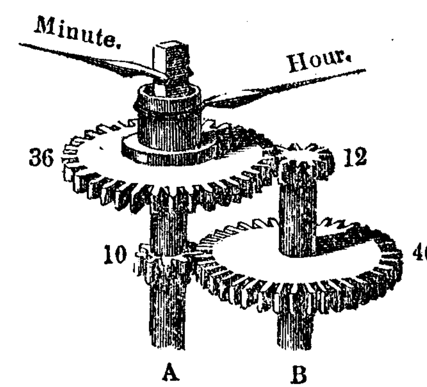
Having seen how the motions are regulated, we may consider the rate of revolution in the wheels, according to the number of leaves in the pinions, or of the teeth in the circumference of the wheels. The central wheel, A, that which is moved by the fusee, has sixty-four teeth; these fall into the pinion of the third wheel, B, which has eight leaves, the wheel itself having sixty teeth; these sixty teeth play into the pinion of the fourth wheel, C, which has eight leaves. The central wheel going round once in the hour, the fourth wheel will go round sixty times in an hour, and with the hand attached to its axle it will mark seconds. This will be more easily un-



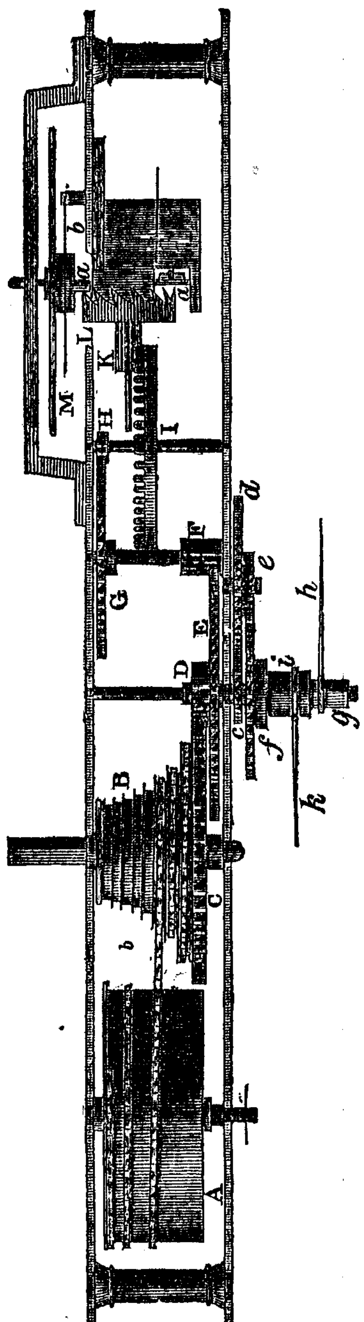
derstood by a reference to the sketch. The wheel on the axis, A, to which the minute-hand is attached, turns round once in an hour. Its sixty-four teeth play upon the pinion on the axle, B; as this has eight leaves, it

will revolve once for every eight teeth of A, and consequently eight times during the whole revolution of A, that is, in an hour. The wheel on the same axle, B, has sixty teeth, which turn the eight-leaved pinion of C; it will, therefore, turn the axle, C, seven times and a half (for $60 \div 8 = 7\frac{1}{2}$) during one revolution, or sixty times during the eight revolutions which B makes in one hour.

Thus we have the minute-hand and the second-hand measuring minutes and seconds of time on the dial; but we have not yet the hand which shall go round in twelve hours and mark the hours on the dial. To effect this the same machinery is used: viz., the wheel and pinion; but the moving power is applied so as to diminish the rate of motion—that is, by making the force act from the leaves of the pinions to the teeth of the wheels, instead of from the teeth to the leaves.



We may remember that the centre wheel, A, goes round once in an hour; that the axle of this wheel passes through the dial and has the minute-hand attached to it. The pinion of this wheel, called the *cannon pinion*, has ten leaves, which play, during the hour, upon a wheel, B, having forty teeth, which accordingly is moved round only once in four hours. This wheel, B, has a pinion of twelve leaves working into a wheel of thirty-six teeth, and must therefore make three revolutions to cause that



Description of the Engraving.

A, the barrel; B, the fusee; *b*, a flexible steel chain which communicates the motion of the barrel to the fusee; C, the great wheel; D, the pinion (called the cannon pinion) of the second or centre wheel, designed to revolve once in an hour; E, the centre wheel, containing sixty-four teeth; F, pinion of the third wheel, containing eight leaves; G, third wheel, containing sixty teeth; H, pinion of fourth wheel, containg eight leaves; I, fourth wheel, containing sixty teeth; K, pinion of the balance wheel (sometimes called the scapement wheel), containing six leaves; L, the balance wheel, containing fifteen teeth, which operate upon the pallets of the balance, and give to it its oscillating motion; *a a*, the pallets; M, the balance; *b*, the hair spring; *c d e f*, minute wheels; *e*, pinion of ten teeth, revolving once in an hour; *d*, wheel of forty teeth, revolving once in four hours; *e*, pinion of twelve leaves; *f*, wheel of thirty-six teeth, revolving once in twelve hours; *g*, the end of the axis of the centre wheel upon which the minute hand *h* revolves; *i*, the axis of the hour wheel upon which the hour hand goes round once in twelve hours.

to revolve once. But as the former, B, requires four hours for one revolution, it must occupy twelve in making three: and consequently the thirty-six toothed wheel will take twelve hours to complete one. To its axle, therefore, the index is attached, which we call the hour-hand of the watch. The axle is a cylinder which incloses the axle of the minute-hand, so that both revolve, indicating the hours and minutes on the same circle of the dial.

It has taken some hundred years to perfect a common time-piece, and the account of the successive improvements is very curious.

In conclusion, we perceive the dependence of the wheels of a watch upon each other; they are nothing singly; they have no energy inherent in them. In the animal frame it is otherwise; each distinct portion has a quality belonging to it, which stands in relation to the quality of some other part.

Were any property different from that of form, which gives the mechanical power, possessed by part of the watch, it might derange the movements. It would be foolish to imagine any endowment like that of life, but we may suppose some such property as polarization, or magnetism, added to a wheel or lever: what could result but disturbance of the mechanical adjustment? We take the following felicitous example:—

A watchmaker had put into his hands a time-piece; but notwithstanding the excellence of the workmanship, it went irregularly. He took the work to pieces and put it together twenty times: no defect could be discovered, and yet it was imperfect,—it was a bad watch! At last, it occurred to him that the defect must be in the balance-wheel (which we have seen to be the regulator of the watch); he thought it possible that this part had become magnetized, and on applying a needle to it he found his suspicion true. By coming accidentally into contact with a magnet, the metal of the balance-wheel had acquired an attraction for the steel work of the watch. A property, superadded to a part of the watch, and at variance with the principle of mechanics on which the machinery was constructed, thus deranged the whole.*

* We have taken the illustration from Cecil's 'Remains,' as quoted by Dr. Latham in his Lectures. The author uses it to explain the effect of a certain bias or predilection in the mind, which deranges the otherwise sound reasoning.

ANIMAL MECHANICS,

OR,

PROOFS OF DESIGN IN THE ANIMAL FRAME.

BY SIR CHARLES BELL.

PUBLISHED UNDER THE SUPERINTENDENCE OF THE SOCIETY FOR THE DIFFUSION OF USEFUL KNOWLEDGE.

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PART I.

THE PERFECTION OF DESIGN IN THE BONES OF THE HEAD, SPINE, AND CHEST, SHOWN BY COMPARISON WITH ARCHITECTURAL AND MECHANICAL CONTRIVANCES.

INTRODUCTION.

To prepare us for perceiving design in the various internal structures of an animal body, we must first of all know that perfect security against accidents is not consistent with the scheme of nature. A liability to pain and injury only proves how entirely the human body is formed with reference to the mind; since, without the continued call to exertion, which danger and the uncertainty of life infer, the development of our faculties would be imperfect, and the mind would remain, as it were, uneducated.

The contrivances (as we should say of things of art) for protecting the vital organs are not absolute securities against accidents; but they afford protection in that exact measure or degree calculated to resist the shocks and pressure to which we are exposed in the common circumstances of life. A man can walk, run, leap, and swim, because the texture of his frame, the strength and power of his limbs, and the specific gravity of his body, are in relation with all around him. But, were the atmosphere lighter, the earth larger, or its attraction more—were he, in short, an inhabitant of another planet, there would be no correspondence between the strength, gravity, and muscular power of his body, and the elements around him, and the balance in the chances of life would be destroyed.

Without such considerations the reader would fall into the mistake, that weakness and liability to fracture imply imperfection in the frame of the body, whereas a deeper contemplation of the subject will convince him of the incomparable perfection both of the plan and of the execution. The body is intended to be subject to derangement and accident, and to become, in the course of life, more and more fragile, until, by some failure in the frame-work or vital actions, life terminates.

And this leads us to reflect on the best means of informing ourselves of the intention or design shown in this fabric. Can there be any better mode of raising our admiration than by comparing it with things of human invention? It must be allowed that we shall not find a perfect analogy. If we compare it with the forms of architecture—the house or the bridge are not built for motion, but for solidity and firmness, on the principle of gravitation. The ship rests in equilibrium prepared for passive motion, and the contrivances of the ship-builders are for resisting an external force: whilst in the animal body we perceive securities against the gravitation of the parts, provisions to withstand shocks and injuries from without, at the same time that the frame-work is also calculated to sustain an internal impulse from the muscular force which moves the bones as levers, or, like a hydraulic engine, propels the fluids through the body.

As in things artificially contrived, lightness and motion are balanced against solidity and weight, it is the same in the animal body. A house is built on a foundation immoveable, and the slightest shift of the ground, followed by the ruin of the house, brings no discredit on the builder; for he proceeds on the certainty of strength from gravitation on a fixed foundation. But a ship is built with reference to motion, to receive an impulse from the wind, and to move through the water. In comparison with the fabric founded on the fixed and solid ground, it becomes subjected to new influences, and in proportion as it is fitted to move rapidly in a light breeze, it is exposed to founder in the storm. A log of wood, or a Dutch dogger almost as solid as a

log, is comparatively safe in the trough of the sea during a storm—when a bark, slightly built and fitted for lighter breezes, would be shaken to pieces: that is to say, the masts and rigging of a ship (the provisions for its motion) may become the source of weakness, and, perhaps, of destruction; and safety is thus voluntarily sacrificed in part, to obtain another property of motion.

So in the animal body: sometimes we see the safety of parts provided for by strength calculated for inert resistance; but when made for motion, when light and easily influenced, they become proportionally weak and exposed, unless some other principle be admitted, and a different kind of security substituted for that of weight and solidity: still a certain insecurity arises from this delicacy of structure.

We shall afterwards have occasion to show that there is always a balance between the power of exertion and the capability of resistance in the living body. A horse or a deer receives a shock in alighting from a leap; but still the inert power of resisting that shock bears a relation to the muscular power with which they spring. And so it is in a man: the elasticity of his limbs is always accommodated to his activity; but it is obvious, that in a fall, the shock, which the lower extremities are calculated to resist, may come on the upper extremity, which, from being adapted for extensive and rapid motion, is incapable of sustaining the impulse, and the bones are broken or displaced.

The analogy between the structure of the human body and the works of human contrivance, which we have to bring in illustration of the designs of nature, is, therefore, not perfect: since sometimes the material is different, sometimes the end to be attained is not precisely the same; and, above all, in the animal body a double object is often secured by the structure or framework, which cannot be accomplished by mere human ingenuity, and of which, therefore, we can offer no illustration strictly correct.

However ingenious our contrivances may be, they are not only limited, but they present a sameness which becomes tiresome. Nature, on the contrary, gives us the same objects of interest, or images of beauty, with such variety, that they lose nothing of their influence and their attraction by repetition.

If the reader has an imperfect notion of design and providence, from a too careless survey of external nature, and the consequent languor of his reflections, we hope that the mere novelty of the instances we are about to place before him may carry conviction to his mind; for we are to draw from nature still, but in a field which has been left strangely neglected, though the nearest to us of all, and of all the most fruitful.

Men proceed in a slow course of advancement in architectural, or mechanical, or optical sciences; and when an improvement is made, it is found that there are all along examples of it in the animal body, which ought to have been marked before, and which might have suggested to us the improvement. It is surprising that this view of the subject has seldom, if ever, been taken seriously, and never pursued. Is the human body formed by an all-perfect Architect, or is it not? And, if the question be answered in the affirmative, does it not approach to something like infatuation, that possessing such perfect models as we have in the anatomy of the body, we yet have been so prone to neglect them?

We undertake to prove, that the foundation of the Eddystone lighthouse, the perfection of human architecture and ingenuity, is not formed on principles so correct as those which have directed the arrangement of the bones of the foot; That the most perfect pillar or kingpost is not adjusted with the accuracy of the hollow bones which support our weight; That the insertion of a ship's mast into the hull is a clumsy contrivance compared with the connexions of the human spine and pelvis; And that the tendons are composed in a manner superior to the last patent cables of Huddart, or the yet more recently improved chain-cables of Bloxam.

Let us assume that the head is the noblest part; and let us examine the carpentry and architectural contrivances exhibited there.

But, before we give ourselves up to the interest of this subject, it will gratify us to express our conviction, that the perfection of the plan of animal bodies, the demonstration of contrivance and adaptation, but more than these, the proof of the continual operation of the power which originally created the system, are evinced in the property of life,—in the adjustment of the various sensibilities,—in the fine order of the moving parts of the body,—in the circulation of living blood,—in the continual death of particles, and their removal from the frame,—in the permanence of the individual whilst every material particle of his frame is a thousand times* changed in the progress of his life. But this is altogether a distinct inquiry, and we are deterred from touching upon it, not more from knowing that our readers are not initiated into it, than from the depth and very great difficulty of the subject.

* The old philosophers gave out that the human body was seven times changed during the natural life. Modern discoveries have shown that the hardest material of the frame is changing continually; that is, every instant of time, from birth to death.

CHAPTER I.

ARCHITECTURE OF THE SKULL.

It requires no disquisition to prove that the brain is the most essential organ of the animal system, and being so, we may presume that it must be especially protected. We are now to inquire how this main object is attained?

We must first understand that the brain may be hurt, not only by sharp bodies touching and entering it, but by a blow upon the head, which shall vibrate through it, without the instrument piercing the skull. Indeed, a blow upon a man's head, by a body which shall cause a vibration through the substance of the brain, may more effectually deprive him of sense and motion than if an axe or a sword penetrated into the substance of the brain itself.

Supposing that a man's ingenuity were to be exercised in contriving a protection to the brain, he must perceive that if the case were soft, it would be too easily pierced; that if it were of a glassy nature, it would be chipped and cracked; that if it were of a substance like metal, it would ring and vibrate, and communicate the concussion to the brain.

Further thoughts might suggest, that whilst the case should be made firm to resist a sharp point, the vibrations of that circular case might be prevented by lining it with a softer material; no bell would vibrate with such an incumbrance; the sound would be stopped like the ringing of a glass by the touch of a finger.

If a soldier's head be covered with a steel cap, the blow of a sword which does not penetrate will yet bring him to the ground by the percussion which extends to the brain; therefore, the helmet is lined with leather, and

covered with hair; for, although the hair is made an ornament, it is an essential part of the protection: we may see it in the head-piece of the Roman soldier, where all useless ornament, being despised as frivolous, was avoided as cumbrous.

We now perceive why the skull consists of two plates of bone, one external, which is fibrous and tough, and one internal, dense to such a degree that the anatomist calls it *tabula vitrea* (the glassy table).

Nobody can suppose this to be accidental. It has just been stated, that the brain may be injured in two ways: a stone or a hammer may break the skull, and the depressed part of the bone injure the brain; whilst, on the other hand, a mallet struck upon the head will, without penetrating, effectually deprive the brain of its functions, by causing a vibration which runs round the skull and extends to every portion of its contents.

Were the skull, in its perfect or mature state, softer than it is, it would be like the skull of a child; were it harder than we find it is, it would be like that of an old man. In other words, as in the former it would be too easily pierced, so, in the latter, it would vibrate too sharply and produce concussion. The skull of an infant is a single layer of elastic bone; on the approach to manhood it separates into two tables; and in old age it again becomes consolidated. During the active years of man's life the skull is perfect: it then consists of two layers, united by a softer substance; the inner layer is brittle as glass, and calculated to resist anything penetrating; the outer table is tough, to give consistence, and to stifle the vibration which would take place if the whole texture were uniform and like the inner table.

The alteration in the substance of the bones, and more particularly in the skull, is marvellously ordered to follow the changes in the mind of the creature, from the heedlessness of childhood to the caution of age, and even the helplessness of superannuation.

The skull is soft and yielding at birth; during childhood it is elastic, and little liable to injury from concussion; and during youth, and up to the period of maturity, the parts which come in contact with the ground are thicker, whilst the shock is dispersed towards the sutures (the seams or joinings of the pieces), which are still loose. But when, with advancing years, something tells us to give up feats of activity, and falls are less frequent, the bones lose that nature which would render concussion harmless, and at length the timidity of age teaches man that his structure is no longer adapted to active life.

We must understand the necessity of the double layer of the skull, in order to comprehend another very curious contrivance. The sutures are the lines of union of the several bones which form the *cranium*,* and surround and protect the brain. These lines of union are called *sutures* (from the Latin word for *sewing*), because they resemble seams. If a workman were to inspect the joining of two of the bones of the cranium, he would admire the minute dove-tailing by which one portion of the bone is inserted into, and surrounded by, the other, whilst that other pushes its processes or juttings out between those of the first in the same manner, and the fibres of the two bones are thus interlaced, as you might interlace your fingers. But when you look to the internal surface, you see nothing of this kind; the bones are here laid simply in contact, and this line by anatomists is called *harmonia*, or harmony: architects use the same term to imply the joining by masonry. Whilst the anatomists are thus curious in names, it is provoking to find them negligent of things more interesting. Having overlooked the reason of the difference in the tables of bone, they are consequently blind to the purpose of this difference of the outward and inward part of a suture.

Suppose a carpenter employed upon his own material, he would join a box with minute and regular indentations by dovetailing, because he knows that the material on

* *Cranium*, from a Greek word signifying a helmet. The cranium is the division of the skull appropriated to the protection of the brain; it consists of six bones—the *frontal* (or forehead); two *parietal* (walls or side bones); the *occipital* (back of the head); and two *temporal* (or temple) bones.

which he works, from its softness and toughness, admits of such adjustment of its edges. The processes of the bone shoot into the opposite cavity with an exact resemblance to the foxtail wedge of the carpenter—a kind of tenon and mortice when the pieces are small.

But if a workman in glass or marble were to inclose some precious thing, he would smooth the surfaces and unite them by cement, because, even if he could succeed in indenting the line of union, he knows that his material would chip off on the slightest vibration. The edges of the marble cylinders which form a column are, for the same reason, not permitted to come in contact; thin plates of lead are interposed to prevent the edges, technically termed *arrises*, from chipping off or splitting.

Now apply this principle to the skull. The outer softer tough table, which is like wood, is indented and dovetailed; the inner glassy table has its edges simply laid in contact. It is mortifying to see a course of bad reasoning obscure this beautiful subject. They say that the bone growing from its centre, and diverging, shoots its fibres betwixt those which come in an opposite direction; thus making one of the most curious provisions of nature a thing of accident. Is it not enough to ask such reasoners why there is not a suture on the inside as well as on the out?

The junction of the bones of the head generally being thus exact, and like the most finished piece of cabinet work, let us next inquire whether there be design or contrivance shown in the manner in which each bone is placed upon another.

When we look upon the side of the skull (as in the figure at p. 29), the temporal suture betwixt the bones A and D is formed in a peculiar manner; the lower, or temporal, bone laps over the superior, or parietal, bone. This, too, has been misunderstood: that is to say, the plan of the building of the bones of the head has not been considered; and this joining, called the squamous*

* From *squama*, the Latin for a *scale*, the thin edges lying over each other like the scales of a fish.

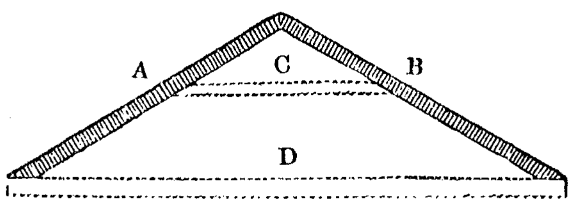
suture, which is a species of scarfing, has been supposed a mere consequence of the pressure of the muscle which moves the jaw.

Dr. Monro says, "the manner how I imagine this sort of suture is formed at these places, is, that by the action of the strong temporal muscles on one side, and by the pressure of the brain on the other, the bones are made so thin that they have not large enough surfaces opposed to each other to stop the extension of their fibres in length, and thus to cause the common serrated appearance of sutures; but the narrow edge of the one bone slides over the other."

The very name of the bones might suggest a better explanation. The *ossa parietalia* * are the two large bones in a regular square, serving as walls to the interior or room of the head, where the brain is lodged.—*See* A *in the foregoing figure.*

Did the reader ever notice how the walls of a house are assisted when thin and overburdened with a roof?

The *wall plate* is a portion of timber built into the wall, to which a transverse or tie-beam is attached by carpentry. This *cogging*, as it is termed, keeps the wall in the perpendicular, and prevents any lateral pressure of the roof. We sometimes see a more clumsy contrivance, a clasp, or a round plate of iron, upon the side of a wall; this has a screw going into the ends of a cross-beam, and by embracing a large portion of the brickwork, it holds the wall from shifting at this point. Or take the instance of a roof supported on inclined rafters, A B:



Were they thus, without further security, placed upon the walls, the weight would tend to spur or press out the

* From the Latin word *paries*, a wall.

walls, which must be strong and heavy to support the roof; therefore, the skeleton of the roof is made into a *truss* (for so the whole joined carpentry is called). The upper cross-beam marked by the dotted lines C, is a collar-beam, connecting the rafters of the roof, and stiffening them, and making the weight bear perpendicularly upon the walls. When the transverse beam joins the extremities of the rafters, as indicated by the lower outline D, it is called a *tie-beam*, and is more powerful still in preventing the rafters from pushing out the walls.

Now when a man bears a burden upon his head, the pressure, or horizontal push, comes upon the lower part of the *parietal bones*, and if they had not a tie-beam, they would, in fact, be spurred out, and the bones of the head be crushed down. But the temporal bone D, and still more, the sphenoid bone E, by running across the base of the skull, and having their edges lapping over the lower part of the great walls, or the parietal bones, lock in the walls as if they had iron plates, and answer the purpose of the tie-beam in the roof, or the iron plate in the walls. But the connexion is at the same time so secure, that these bones act equally as a *straining* piece, that is, as a piece of timber, preventing the tendency of the sides *of the skull* to each other.

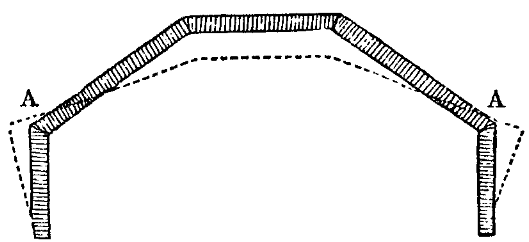
It may be said, that the skull is not so much like the wall of a house as like the arch of a bridge: let us then consider it in this light.

We have here the two parietal bones, separated and resting against each other, so as to form an arch. In the centering, which is the wooden frame for supporting a stone arch while building, there are some principles that are applicable to the head.

We see that the arch formed by the two parietal bones (see fig. at p. 30) is not a perfect semicircle; there is a projection at the centre of each bone, the bone is more convex, and thicker at this part.

The cause assigned for this is, that it is the point from which ossification begins, and where it is, therefore, most perfect. But this is to admit a dangerous principle, that the forms of the bones are matter of chance: and thence we are left without a motive for study, and make no endeavour to comprehend the uses of parts. We find that all the parts which are most exposed to injury are thus strengthened;—the centre of the forehead, the projecting point of the skull behind, and the lateral centres of the parietal and frontal bones. The parts of the head which would strike upon the ground when a man falls are the strongest, and the projecting arch of the parietal bone is a protection to the weaker temporal bone.

If we compare the skull to the *centering*, where a bridge is to be built over a navigable river, and consequently where the space must be free in the middle, we find that the scientific workmen are careful, by a transverse beam, to protect the points where the principal thrust will be made in carrying up the masonry: this beam does not act as a tie-beam, but as a straining-piece, preventing the arch from being crushed in at this point.



The necessity of strengthening certain points is well exhibited in the carpentry of roofs. In this figure it is clear, that the points A A will receive the pressure of the roof, and if the joining of the puncheons* and rafters be not secure, it will sink down in the form of the dotted line. The workmen would apply braces at these angles to strengthen them.

In the arch, and at the corresponding points of the

* The puncheons are the upright lateral pieces; the rafters are the timbers which lie oblique, and join the puncheons at A A.

parietal bones, the object is attained by strengthening these points by increase of their convexity and thickness; and where the workman would support the angles by braces, there are ridges of bone, in the calvaria,* or roof of the skull.

If a stone arch fall, it must give way in two places at the same time; the centre cannot sink unless that part of the arch which springs from the pier yields: and in all arches, from the imperfect Roman arch to that built upon modern principles, the aim of the architect is to give security to this point.

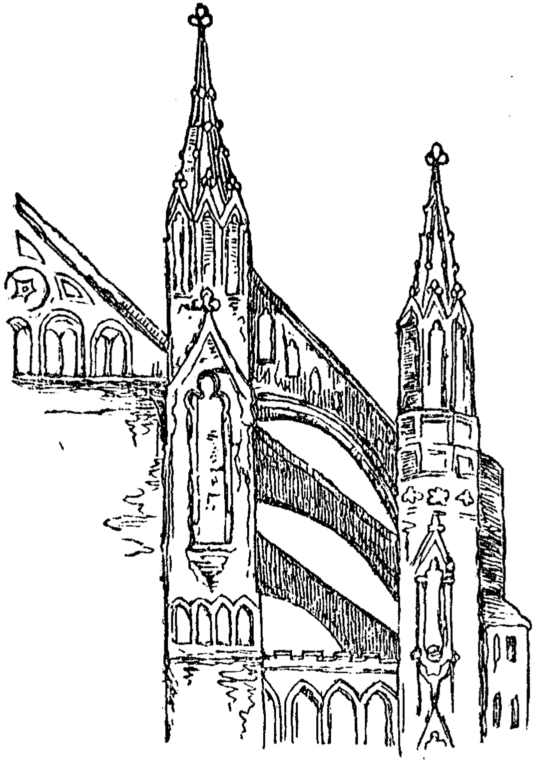
In the Roman bridges still entire the arch rises high, with little inclination at the lower part; and in bridges of a more modern date, we see a mass of masonry erected on the pier, sometimes assuming the form of ornament, sometimes of a tower or gateway, but obviously intended at the same time, by the perpendicular load, to resist the horizontal pressure of the arch. If this be omitted in more modern buildings, it is supplied by a finer art, which gives security to the masonry of the pier (to borrow the terms of anatomy) by its internal structure.

In what is termed Gothic architecture, we see a flying buttress, springing from the outer wall, carried over the roof of the aisle, and abutting against the wall of the upper part, or *clerestory*. From the upright part of this masonry a pinnacle is raised, which at first appears to be a mere ornament, but which is necessary, by its perpendicular weight, to counteract the horizontal thrust of the arch.

By all this, we see that if the skull is to be considered as an arch, and the parietal bones as forming that arch, they must be secured at the temporal and sphenoid†

* From the Latin *calva* or *calvaria*, a *helmet*.

† In the Greek, *sphenoid*—in the Latin, *cuneiform*—like a wedge, because it is wedged among the other bones of the head; but these processes, called wedges, are more like dovetails, which enter into the irregularities of the bones, and hold them locked.



bones, the points from which they spring. And, in point of fact, where is it that the skull yields when a man falls, so as to strike the top of his head upon the ground?—in the temples. And yet the joinings are so secure, that the extremity of the bone does not start from its connexions. It must be fractured before it is spurred out, and in that case only does the upper part of the arch yield.

But the best illustration of the form of the head is the dome.

A dome is a vault rising from a circular or elliptical base; and the human skull is, in fact, an elliptical surmounted dome, which latter term means that the dome is higher than the radius of its base. Taking this matter historically, we should presume that the dome was the

most difficult piece of architecture, since the first dome erected appears to have been at Rome, in the reign of Augustus—the Pantheon, which is still entire. The dome of St. Sophia, in Constantinople, built in the time of the Emperor Justinian, fell three times during its erection: and the dome of the Cathedral of Florence stood unfinished one hundred and twenty years for want of an architect. Yet we may, in one sense, say that every builder who tried it, as well as every labourer employed, had the most perfect model in his own head. It is obvious enough, that the weight of the upper part of the dome must disengage the stones from each other which form the lower circle, and tend to break up their joinings, and consequently to press or thrust outwards the circular wall on which it rests. No walls can support the weight, or rather, the lateral thrust, unless each stone of the dome be soldered to another, or the whole hooped together and girded. The dome of St. Paul's has a very strong double iron chain, linked together, at the bottom of the cone; and several other lesser chains between that and the cupola, which may be seen in the section of St. Paul's engraved by Hooker.

The bones of the head are securely bound together, so that the anatomist finds, when every thing is gone, save the bone itself, and there is neither muscle, ligament, nor membrane of any kind, to connect the bones, they are, still, securely joined, and it requires his art to burst them asunder; and for this purpose he must employ a force which shall produce a uniform pressure from the centre outwards; and all the sutures must receive the pressure at one time and equally, or they will not give way. And now is the time to observe another circumstance, which calls for our admiration. So little of accident is there in the joining of the bones, that the edge of a bone at the suture lies over the adjoining bone at one part and under it at another, which, with the dovetailing of the suture, as before described, holds each bone in its place firmly attached; and it is this which gives security to the dome of the cranium.

If we look at the skull in front, we may consider the orbits of the eye as crypts under the greater building. And these under-arches are groined, that is to say, there are strong arched spines of bone, which give strength sufficient to permit the interstices of the groinings, if I may so term them, to be very thin. Betwixt the eye and the brain, the bone is as thin as parchment; but if the anterior part of the skull had to rest on this, the foundation would be insufficient. This is the purpose of the strong ridge of bone which runs up like a buttress from the temple to the lateral part of the frontal bone, whilst the arch forming the upper part of the orbit is very strong: and these ridges of bone, when the skull is formed with what we call a due regard to security, give an extension to the forehead.*

In concluding this survey of the architecture of the head, let us suppose it so expanded that we could look upon it from within. In looking up to the vault, we should at once perceive the application of the *groin* in masonry; for the groin is that projection in the vault which results from the intersection of two arches running in different directions. One rib or groin extends from the centre of the frontal bone to the most projecting part of the occipital foramen, or opening on the back of the head; the other rib crosses it from side to side of the occipital bone. The point of intersection of these two groins is the thickest and strongest part of the skull, and it is the most exposed, since it is the part of the head which would strike upon the ground when a man falls backwards.

What is termed the base of the skull is strengthened, if we may so express it, on the same principle: it is like a cylinder groin, where the rib of an arch does not terminate upon a buttress or pilaster, but is continued round in the completion of the circle. The base of the skull is irregular, and in many places thin and weak, but these arched spines or ribs give it strength to bear those shocks to which it is of course liable at the joining of the skull with the spine.

* Although they are solid arches connected with the building of the cranium, and bear no relation to the surfaces of the brain, the early craniologists would have persuaded us that their forms correspond with the surfaces of the brain, and indicate particular capacities or talents.

CHAPTER II.

MECHANISM OF THE SPINE.

The brain-case is thus a perfect whole, secure on all sides, and strengthened where the exposure to injury is the greatest. We shall see, in the column which sustains it, equal provision for the security of the brain; and, what is most admirable, there is an entirely different principle introduced here; for whereas in the head, the whole aim is firmness in the joinings of the bones, in the spine which supports the head, the object to be attained is mobility or pliancy. In the head, each bone is firmly secured to another; in the spine, the bones are not permitted to touch: there is interposed a soft and elastic material, which takes off the jar that would result from the contact of the bones. We shall consider this subject a little more in detail.

The spinal column, as it is called, serves three purposes: it is the great bond of union betwixt all the parts of the skeleton; it forms a tube for the lodgment of the spinal marrow, a part of the nervous system as important to life as the brain itself; and lastly, it is a column to sustain the head.

We now see the importance of the spine, and we shall next explain how the various offices are provided for.

If the protection of the spinal marrow had been the only object of this structure, it is natural to infer that it would have been a strong and unyielding tube of bone; but, as it must yield to the inflexions of the body, it cannot be constituted in so strict an analogy with the skull. It must, therefore, bend; but it must have no abrupt or considerable bending at one part; for the spinal marrow within would in this way suffer.

By this consideration we perceive why there are twenty-four bones in the spine, each bending a little; each articulated or making a joint with its fellow; all yielding in a slight degree, and, consequently, permitting in the whole spine that flexibility necessary to the motions of the body. It is next to be observed that, whilst the spine by this provision moves in every direction, it gains a property which it belongs more to our present purpose to understand. The bones of the spine are called vertebræ; at each interstice between these bones there is a peculiar gristly substance, which is squeezed out from betwixt the bones, and, therefore, permits them to approach and play a little in the motions of the body. This gristly substance is inclosed in an elastic binding, or membrane of great strength, which passes from the edge or border of one vertebra to the border of the one next it. When a weight is upon the body, the soft gristle is pressed out, and the membrane yields: the moment the weight is removed, the membranes recoil by their elasticity, the gristle is pressed into its place, and the bones resume their position.

We can readily understand how great the influence of these twenty-four joinings must be in giving elasticity to the whole column; and how much this must tend to the protection of the brain. Were it not for this interposition of elastic material, every motion of the body would produce a jar to the delicate texture of the brain, and we should suffer almost as much in alighting on our feet, as in falling on our head. It is, as we have already remarked, necessary to interpose thin plates of lead or slate between the different pieces of a column to prevent the edges (technically called arrises) of the cylinders from coming in contact, as they would, in that case, chip or split off.

But there is another very curious provision for the protection of the brain: we mean the curved form of the spine. If a steel spring, perfectly straight, be pressed betwixt the hands from its extremities, it will resist, notwithstanding its elasticity, and when it does give way, it will be with a jerk. Such would be the effect on the spine if it stood upright, one bone perpendicular to another; for then the weight would bear equally; the spine would yield neither to one side nor to the other; and, consequently, there would be a resistance from the pressure on all sides being balanced. We, therefore, see the great advantage resulting from the human spine being in the form of an italic *ſ*. It is prepared to yield in the direction of its curves; the pressure is of necessity more upon one side of the column than on the other; and its elasticity is immediately in operation without a jerk. It yields, recoils, and so forms the most perfect spring; admirably calculated to carry the head without jar, or injury of any kind.

The most unhappy illustration of all this is the condition of old age. The tables of the skull are then consolidated, and the spine is rigid: if an old man should fall with his head upon the carpet, the blow, which would be of no consequence to the elastic frame of a child, may to him prove fatal; and the rigidity of the spine makes every step which he takes vibrate to the interior of the head, and jar on the brain.

We have hinted at a comparison betwixt the attachment of the spine to the pelvis and the insertion of the mast of a ship into the hull. The mast goes directly through the decks without touching them, and the heel of the mast goes into the step, which is formed of large solid pieces of oak timber laid across the keelson. The keelson is an inner keel resting upon the floor-timbers of the ship and directly over the proper keel. These are contrivances for enlarging the base on which the mast rests as a column: for as, in proportion to the height and weight of a column, its base must be enlarged, or it would sink into the earth; so, if the mast were to bear upon a point, it would break through the bottom of the ship.

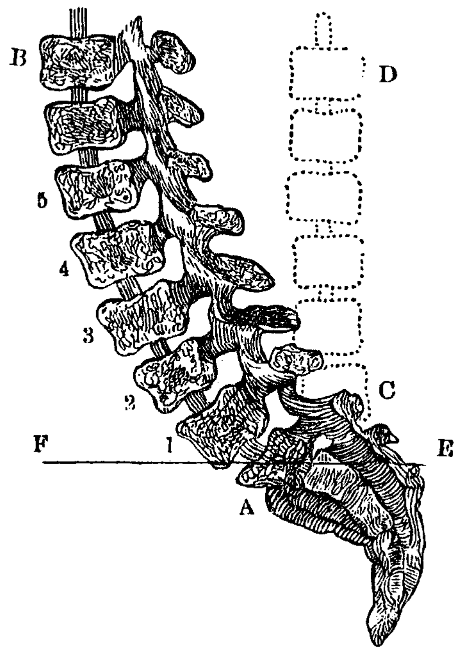
The mast is supported upright by the shrouds and stays. The shrouds secure it against the lateral or rolling motion, and the stays and backstays against the pitching of the ship. These form what is termed the standing rigging. The mast does not bear upon the deck or on the beams of the ship; indeed there is a space covered with canvas betwixt the deck and the mast.

We often hear of a new ship going to sea to stretch her rigging; that is, to permit the shrouds and stays to be stretched by the motion of the ship, after which they are again braced tight: for if she were overtaken by a storm before this operation, and when the stays and shrouds were relaxed, the mast would lean against the upper deck, by which it would be sprung or carried away. Indeed, the greater proportion of masts that are lost are lost in this manner. There are no boats which keep the sea in such storms as those which navigate the gulf of Finland. Their masts are not attached at all to the hull of the ship, but simply rest upon the step.

Although the spine has not a strict resemblance to the mast, the contrivances of the ship-builder, however different from the provisions of nature, show what object is to be attained; and when we are thus made aware of what is necessary to the security of a column on a moveable base, we are prepared to appreciate the superior provisions of nature for giving security to the human spine.

The human spine rests on what is called the *pelvis*, or basin;—a circle of bones, of which the haunches are the extreme lateral parts; and the sacrum (which is as the keystone of the arch) may be felt at the lower part of the back. To this central bone of the arch of the pelvis the spine is connected; and, taking the similitude of the mast, the sacrum is as the *step* on which the base of the pillar, like the heel of the mast, is socketed or mortised. The spine is tied to the lateral parts of the pelvis by powerful ligaments, which may be compared to the shrouds. They secure the lower part of the spine against the shock of lateral motion or rolling; but, instead of the stays to limit the play of the spine forwards and backwards in pitching, or to adjust the rake of the mast, there is a very beautiful contrivance in the lower part of the column.

The spine forms here a semicircle which has this effect; that, whether by the exertion of the lower extremities, the spine is to be carried forward upon the pelvis, or whether the body stops suddenly in running, the jar which would necessarily take place at the lower part of the spine A, if it stood upright like a mast, is distributed over several of the bones of the spine, 1, 2, 3, 4, and, therefore, the chance of injury at any particular part is diminished.



For example, the sacrum, or centre bone of the pelvis, being carried forward, as when one is about to run, the force is communicated to the lowest bone of the spine. But, then, the surfaces of these bones stand with a very slight degree of obliquity to the line of motion; the shock communicated from the lower to the second bone of the vertebræ is still in a direction very nearly perpendicular to its surface of contact. The same takes place in the communication of force from the second to the third, and from the third to the fourth; so that before the shock of the horizontal motion acts upon the perpendicular spine, it is distributed over four bones of that

column, instead of the whole force being concentrated upon the joining of any two, as at A.

If the column stood upright, as indicated at C D, it would be jarred at the lowest point of contact with its base. But by forming a semicircle A B, the motion which in the direction E F would produce a jar on the very lowest part of the column, is distributed over a considerable portion of the column A B; and in point of fact, this part of the spine never gives way. Indeed, we should be inclined to offer this mode to the consideration of nautical men, as fruitful in hints for improving naval architecture.

Every one who has seen a ship pitching in a heavy sea, must have asked himself why the masts are not upright, or rather, why the foremast stands upright, whilst the main and mizen masts stand oblique to the deck, or, as the phrase is, rake aft or towards the stern of the ship.

The main and mizen masts incline backwards, because the strain is greatest in the forward pitch of the vessel; for the mast having received an impulse forwards, it is suddenly checked as the head of the ship rises; but the mast being set with an inclination backwards, the motion falls more in the perpendicular line from the head to the heel. This advantage is lost in the upright position of the foremast, but it is sacrificed to a superior advantage gained in working the ship; the sails upon this mast act more powerfully in swaying the vessel round, and the perpendicular position causes the ship to tack or stay better; but the perpendicular position, as we have seen, causes the strain in pitching to come at right angles to the mast, and is, therefore, more apt to spring it.

These considerations give an interest to the fact, that the human spine, from its utmost convexity near its base, inclines backwards.

CHAPTER III.

OF THE CHEST.

In extending the parallel which we proposed between the structure of the body and the works of human art, it signifies very little to what part we turn; for the happy adaptation of means to the end will everywhere challenge our admiration, in exact proportion to our success in comprehending the provisions which Supreme Wisdom has made. We turn now to a short view of the bones of the chest.

The thorax, or chest, is composed of bones and cartilages, so disposed as to sustain and protect the most vital parts, the heart and lungs, and to turn and twist with perfect facility in every motion of the body; and to be in incessant motion in the act of respiration, without a moment's interval during a whole life. In anatomical description, the thorax is formed of the vertebral column, or spine, on the back part, the ribs on either side, and the breastbone, or sternum, on the fore part. But the thing most to be admired is the manner in which these bones are united, and especially the manner in which the ribs are joined to the breastbone, by the interposition of cartilages, or gristle, of a substance softer than bone, and more elastic and yielding. By this quality they are fitted for protecting the chest against the effects of violence, and even for sustaining life after the muscular power of respiration has become too feeble to continue without this support.

If the ribs were complete circles, formed of bone, and extending from the spine to the breastbone, life would be endangered by any accidental fracture; and even the rubs and jolts to which the human frame is continually

exposed, would be too much for their delicate and brittle texture. But these evils are avoided by the interposition of the elastic cartilage. On their forepart the ribs are eked out, and joined to the breastbone by means of cartilages, of a form corresponding to that of the ribs, being, as it were, a completion of the arch of the rib, by a substance more adapted to yield in every shock or motion of the body. The elasticity of this portion subdues those shocks which would occasion the breaking of the ribs. We lean forward, or to one side, and the ribs accommodate themselves, not by a change of form in the bones, but by the bending or elasticity of the cartilages. A severe blow upon the ribs does not break them, because their extremities recoil and yield to the violence. It is only in youth, however, when the human frame is in perfection, that this pliancy and elasticity have full effect. When old age approaches, the cartilages of the ribs become bony. They attach themselves firmly to the breastbone, and the extremities of the ribs are fixed, as if the whole arch were formed of bone unyielding and inelastic. Then every violent blow upon the side is attended with fracture of the rib, an accident seldom occurring in childhood, or in youth.

But there is a purpose still more important to be accomplished by means of the elastic structure of the ribs, as partly formed of cartilage. This is in the action of breathing, or respiration; especially in the more highly-raised respiration which is necessary in great exertions of bodily strength, and in violent exercise. There are two acts of breathing—*expiration*, or the sending forth of the breath; and *inspiration*, or the drawing in of the breath. When the chest is at rest, it is neither in the state of expiration nor in that of inspiration; it is in an intermediate condition between these two acts. And the muscular effort by which either inspiration or expiration is produced is an act in opposition to the elastic property of the ribs. The property of the ribs is to preserve the breast in the intermediate state between expiration and inspiration. The muscles of respiration are excited alternately, to dilate or to contract the cavity of the chest, and, in doing so, to raise or to depress the ribs. Hence it is, that both in inspiration and in expiration the elasticity of the ribs is called into play; and, were it within our province, it would be easy to show, that the dead power of the cartilages of the ribs preserves life by respiration, after the vital muscular power would, without such assistance, be too weak to continue life.

It will at once be understood, from what has now been explained, how, in age, violent exercise or exertion is under restraint, in so far as it depends on respiration. The elasticity of the cartilages is gone, the circle of the ribs is now unyielding, and will not allow that high breathing, that sudden and great dilating and contracting of the cavity of the chest, which is required for circulating the blood through the lungs, and relieving the heart amidst the more tumultuous flowing of the blood which exercise and exertion produce.

CHAPTER IV.

DESIGN SHOWN IN THE STRUCTURE OF THE BONES AND JOINTS OF THE EXTREMITIES.

THAT the bones, which form the interior of animal bodies, should have the most perfect shape, combining strength and lightness, ought not to surprise us, when we find this in the lowest vegetable production.

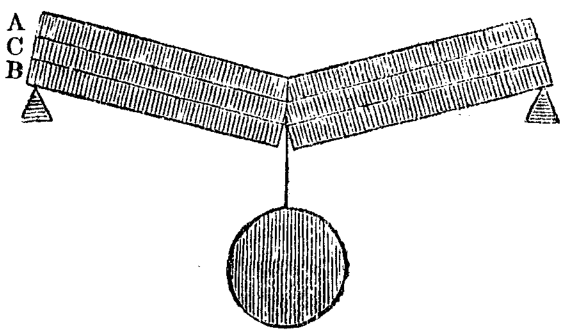
In the sixteenth century, an unfortunate man who taught medicine, philosophy, and theology, was accused of atheistical opinions, and condemned to have his tongue cut out, and to suffer death. When brought from his cell before the Inquisition, he was asked if he believed in God. Picking up a straw which had stuck to his garments, "If," said he, "there was nothing else in nature to teach me the existence of a Deity, even this straw would be sufficient!"*

[A reed, or a quill, or a bone, may be taken to prove that in Nature's works strength is given with the least possible expense of materials. The long bones of animals are, for the most part, hollow cylinders, filled up with the lightest substance, marrow; and in birds the object is attained by means (if we may be permitted to say so) still more artificial. Every one must have observed, that the breast-bone of a fowl extends along the whole body, and that the body is very large compared with the weight: this is for the purpose of rendering the creature specifically lighter and more buoyant in the air; and that it may have a surface for the attachment of muscles, equal to the exertion of raising it on the wing. This combina-

* The passage following, marked in brackets, on to p. 189, appears also in Sir C. Bell's Illustrations of Paley, p. 18. It could not be removed from its present place without disturbing the coherence of the argument.

tion of lightness with increase of volume is gained by air-cells extending through the body, and communicating by tubes between the lungs and cavities of the bones. By these means, the bones, although large and strong to withstand the operation of powerful muscles upon them, are much lighter than those of quadrupeds.

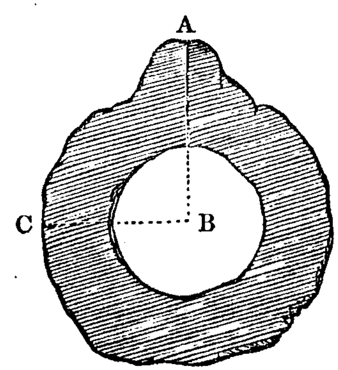
The long bones of the human body, being hollow tubes, are called cylindrical, though they are not accurately so, the reason of which we shall presently explain; and we shall, at the same time, show that their irregularities are not accidental, as some have imagined. But let us first demonstrate the advantage which, in the structure of the bones, is derived from the cylindrical form, or a form approaching to that of the cylinder. If a piece of timber supported on two points, thus—



bear a weight upon it, it sustains this weight by different qualities in its different parts. For example, divide it into three equal parts (A, B, C): the upper part A supports the weight by its solidity and resistance to compression; the lowest part B, on the other hand, resists by its toughness, or adhesive quality. Betwixt the portions acting in so different a manner there is an intermediate neutral, or central part C, that may be taken away without materially weakening the beam, which shows that a hollow cylinder is the form of strength. The Writer lately observed a good demonstration of this:—a large tree was blown down, and lay upon the ground; to the windward, the broken part gaped; it had been torn asunder like the snapping of a rope: to the leeward side of the tree, the fibres of the stem were crushed into one

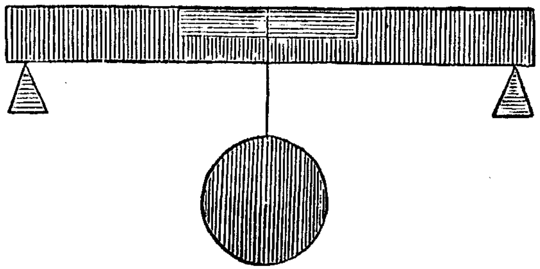
another and splintered; whilst the central part remained entire. This, we presume, must be always the case, more or less; and here we take the opportunity of noticing why the arch is the form of strength. If this transverse piece of timber were in the form of an arch, and supported at the extremities, then its whole thickness, its centre, as well as the upper and lower parts, would support weight by resisting compression. But the demonstration may be carried much farther to show the form of strength in the bone. If the part of the cylinder which bears the pressure be made more dense, the power of resistance will be much increased; whereas, if a ligamentous covering be added on the other side, it will strengthen the part which resists extension: and we observe a provision of this kind in the tough ligaments which run along the vertebræ of the back.

When we see the bone cut across, we are forced to acknowledge that it is formed on the principle of the cylinder; that is, that the material is removed from the centre, and accumulated on the circumference, thus—



We find a spine, or ridge running along the bone, which, when divided by the saw in a transverse direction, exhibits an irregularity, as at A.

The section of this spine shows a surface as dense as ivory, which is, therefore, much more capable of resisting compression than the other part of the cylinder, which is common bone. This declares what the spine is, and the anatomists must be wrong who imagine that the bone is moulded by the action of the muscle, and that the spine is a mere ridge, arising by accident among the muscles. It is, on the contrary, a strengthening of the bone in the direction on which the weight bears. If we resume the experiment with the piece of timber, we shall learn why the spine is harder than the rest of the bone. If a portion of the upper part of the timber be cut away, and a harder wood inserted in its place, the beam will acquire a new power of resisting fracture, because, as we have stated, this part of the wood does not yield but by being crushed, and the insertion of the



harder portion of wood increases this property of resistance. With this fact before us we may return to the examination of the spine of bone. We see that it is calculated to resist pressure, first, because it is farther removed from the centre of the cylinder; and, secondly, because it is denser, to resist compression, than the other part of the circumference of the bone.*

This explanation of the use of a spine upon a bone gives a new interest to osteology.† The anatomist ought to deduce from the form of the spine the motions of the limb; the forces bearing upon the bone, and the nature and the common place of fracture; while to the general inquirer an agreeable process of reasoning is introduced in that department, which is altogether without interest when the "*irregularities*" of the bone are spoken of, as

* As the line A B extends farther from the centre than B C, on the principle of a lever, the resistance to transverse fracture will be greater in the direction A B than B C.

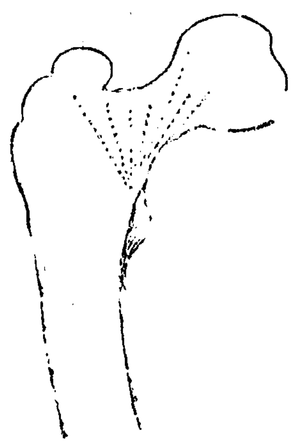
† *Osteology*, from the Greek words, signifying discourse on bone, being the demonstration of the forms and connexion of the different bones.

if they were the accidental consequences of the pressure of the flesh upon it.

Although treating of the purely mechanical principle, it is, perhaps, not far removed from our proper object to remark, that a person of feeble texture and indolent habits has the bone smooth, thin, and light; but that Nature, solicitous for our safety, in a manner which we could not anticipate, combines with the powerful muscular frame a dense and perfect texture of bone, where every spine and tubercle is completely developed. And thus the inert and mechanical provisions of the bone always bear relation to the muscular power of the limb, and exercise is as necessary to the perfect constitution of a bone as it is to the perfection of the muscular power. Jockeys speak correctly enough, when they use the term "*blood and bone*," as distinguishing the breed or genealogy of horses; for blood is an allowable term for the race, and bone is so far significant, that the bone of a running horse is remarkably compact compared with the bone of a draught horse. The reader can easily understand, that the span in the gallop must give a shock in proportion to its length; and as in man, so in the horse, the greater the muscular power the denser and stronger is the bone.

The bone not being as a mere pillar, intended to bear a perpendicular weight, we ought not to expect uniformity in its shape. Each bone, according to its place, bears up against the varying forces that are applied to it. Consider two men wrestling together, and then think how various the property of resistances must be: here they are pulling, and the bones are like ropes; or again, they are writhing and twisting, and the bones bear a force like the axle-tree between two wheels; or they are like a pillar under a great weight; or they are acting as a lever.]

To withstand these different shocks, a bone consists of three parts, the *earth* of bone (sub-phosphate of lime); *fibres* to give it toughness; and *cartilage* to give it elasticity. These ingredients are not uniformly mixed up in all bones; but some bones are hard, from the prevalence of the earth of bone; some more fibrous, to resist a pull upon them; and some more elastic, to resist the shocks in walking, leaping, &c. But to return to the forms:—Whilst the centre of the long bones is, as we have stated, cylindrical, their extremities are expanded, and assume various shapes. The expansion of the head of the bone is to give a greater, and consequently a more secure surface for the joint, and its form regulates the direction in which the joint is to move. A jockey, putting his hand on the knee of a colt, and finding it broad and flat, augurs the perfection of the full-grown horse. To admit of this enlargement and difference of form, a change in the internal structure of the bone is necessary, and the hollow of the tube is filled up with *cancelli*, or lattice-work. These *cancelli* of the bone are minute and delicate, like wires, which form lattice-work, extending in all directions through the interior of the bone, and which, were it elastic, would be like a sponge.—This more uniform texture of the bone permits the outer shell to be very thin, so that whilst the centre of the long bones are cylinders, their extremities are of a uniform cancellated structure. But it is pertinent to our purpose to notice, that this minute lattice-work, or the cancelli which constitute the interior structure of bone, have still reference to the forces acting on the bone; if any



The head of the thigh-bone, to show the direction of the *cancelli*, converging to the line of gravity.

one doubts this, let him make a section of the upper and lower end of the thigh-bone, and let him inquire what is the meaning of the difference in the *lie* of these minute bony fibres, in the two extremities? He will find that the head of the thigh-bone stands obliquely off from the shaft, and that the whole weight bears on what is termed the *inner trochanter:* and to that point, as to a buttress, all these delicate fibres converge, or point from the head and neck of the bone, which may be rudely represented in this way. (See fig., p. 190.)

We may here notice an opinion that has been entertained, in regard to the size of animals. It is believed that the material of bone is not capable of supporting a creature larger than the elephant, or the *mastodon*, which is the name of an extinct animal of great size, the osseous remains of which are still found. This opinion is countenanced by observing that their bones are very clumsy, that their spines are of great thickness, and that their hollow cylinders are almost filled up with bone.

It may be illustrated in this manner;—A soft stone projecting from a wall may make a stile, strong enough to bear a person's weight; but if it were necessary to double its length, the thickness must be more than doubled, or a freestone substituted; and were it necessary to make this freestone project twice as far from the wall, even if doubled in thickness, it would not be strong enough to bear a proportioned increase of weight: granite must be placed in its stead; and even the granite would not be capable of sustaining four times the weight which the soft stone bore in the first instance. In the same way the stones which form an arch of a large span must be of the hardest granite, or their own weight would crush them. The same principle is applicable to the bones of animals. The material of bone is too soft to admit an indefinite increase of weight; and it is another illustration of what was before stated, that there is a relation established through all nature, and that the very animals which move upon the surface of the earth are proportioned *to its magnitude*, and the gravitation to its centre. Archdeacon Paley has with great propriety taken the instance of the form of the ends of bones, as proving design in the mechanism of a joint. But there is something so highly interesting in the conformation of the whole skeleton of an animal, and the adaptation of any one part to all the other parts, that we must not let our readers remain ignorant of the facts, or of the important conclusions drawn from them.

What we have to state has been the result of the studies of many naturalists; but although they have laboured, as it were, in their own department of comparative anatomy, they have failed to seize upon it with the privilege of genius, and to handle it in the masterly manner of Cuvier.

Suppose a man ignorant of anatomy to pick up a bone in an unexplored country, he learns nothing, except that some animal has lived and died there; but the anatomist can, by that single bone, estimate, not merely the size of the animal, as well as if he saw the print of its foot, but the form and joints of the skeleton, the structure of its jaws and teeth, the nature of its food, and its internal economy. This, to one ignorant of the subject, must appear wonderful, but it is after this manner that the anatomist proceeds: let us suppose that he has taken up that portion of bone in the limb of the quadruped which corresponds to the human wrist; and that he finds that the form of the bone does not admit of free motion in various directions, like the paw of the carnivorous creature. It is obvious, by the structure of the part, that the limb must have been merely for supporting the animal, and for progression, and not for seizing prey. This leads him to the fact that there were no bones resembling those of the hand and fingers, or those of the claws of the tiger; for the motions which that conformation of bones permits in the paw would be useless without the rotation of the wrist—he concludes that these bones were formed in one mass, like the cannon-bone, pastern-bone, and coffin-bones of the horse's foot.*

* For these are solid bones, where it is difficult to recognise any resemblance to the carpus, metacarpus, and bones of the fingers; and yet comparative anatomy proves that these moveable bones are of the same class with those in the solid hoof of the *belluæ* of Linnæus.

The motion limited to flexion and extension of the foot of a hoofed animal implies the absence of a collar-bone, and a restrained motion in the shoulder joint; and thus the naturalist, from the specimen in his hand, has got a perfect notion of all the bones of the anterior extremity! The motions of the extremities imply a condition of the spine which unites them. Each bone of the spine will have that form which permits the bounding of the stag, or the galloping of the horse, but it will not have that form of joining which admits the turning or writhing of the spine, as in the leopard or the tiger.

And now he comes to the head:—the teeth of a carnivorous animal, he says, would be useless to rend prey, unless there were claws to hold it, and a mobility of the extremities like the hand, to grasp it. He considers, therefore, that the teeth must have been for bruising herbs, and the back teeth for grinding. The socketing of these teeth in the jaw gives a peculiar form to these bones, and the muscles which move them are also peculiar; in short, he forms a conception of the shape of the skull. From this point he may set out anew, for by the form of the teeth he ascertains the nature of the stomach, the length of the intestines, and all the peculiarities which mark a vegetable feeder.

Thus the whole parts of the animal system are so connected with one another, that from one single bone or fragment of bone, be it of the jaw, or of the spine, or of the extremity, a really accurate conception of the shape, motions, and habits of the animal, may be formed.

It will readily be understood that the same process of reasoning will ascertain, from a small portion of a skeleton, the existence of a carnivorous animal, or of a fowl, or of a bat, or of a lizard, or of a fish; and what a conviction is here brought home to us, of the extent of that plan which adapts the members of every creature to its proper office, and yet exhibits a system extending through the whole range of animated beings, whose motions are conducted by the operation of muscles and bones.

After all, this is but a part of the wonders disclosed through the knowledge of a thing so despised as a fragment of bone. It carries us into another science; since the knowledge of the skeleton not only teaches us the classification of creatures now alive, but affords proofs of the former existence of animated beings which are not now to be found on the surface of the earth. We are thus led to an unexpected conclusion from such premises: not merely the existence of an individual animal, or race of animals; but even the changes which the globe itself has undergone in times before all existing records, and before the creation of human beings to inhabit the earth, are opened to our contemplation.

Of Standing.

This may appear to some a very simple inquiry, and yet it is very ignorant to suppose that it is so. The subject has been introduced in this fashion:—"Observe these men engaged in raising a statue to its pedestal with the contrivances of pulleys and levers, and how they have placed it on the pedestal and are soldering it to keep it steady, lest the wind should blow it down. This statue has the fair and perfect proportions of the human body; to all outward appearance it ought to stand."

In the following passage we have the same idea thrown out in a manner which we are apt to call *French*. Were a man cast on a desert shore, and there to find a beautiful statue of marble, he would naturally exclaim,—"Without doubt, there have been inhabitants here: I recognise the hand of a famous sculptor: I admire the delicacy with which he has proportioned all the members of the body to give them beauty, grace, and majesty, to indicate the motion and expression of life." But it may be asked, what would such a man think if his companion were to say,—"Not at all—no sculptor made this statue; it is formed, to be sure, in the best taste, and according to the rules of art, but it is formed by chance: amongst the many fragments of marble, there has been one thus formed of itself. The rain and the winds have detached it from the mountain, and a storm has placed it upright on the pedestal. The pedestal, too, was prepared of itself in this lonely place. True, it is like the Apollo, or

the Venus, or the Hercules. You might believe that the figure lived and thought; that it was prepared to move and speak; but it owes nothing to art; blind chance has placed it there." *

The first passage suggests the conviction that the power of standing proceeds not from any symmetry, as in a pillar, or from gravitation alone. It, in fact, proceeds from an internal provision, by which a man is capable of estimating, with great precision, the inclination of his body, and correcting the bias by the adjustment of the muscles. In the second passage, it is meant to be shown that the outward proportion of the form bears a relation to the internal structure; that grace and expression are not superficial qualities, and that only the Divine Architect could form such a combination of animated machinery.

We shall consider how the human body is prepared by mechanical contrivances to stand upright, and by what fine sense of the gravitation of the body the muscles are excited to stiffen the otherwise loose joints, and to poise the body on its base.

Of the Foot.

Let us take the arrangement of the bones of the foot, according to the demonstration of the anatomists.

They are divided into the *tarsus*, which is composed of seven bones, reaching from the heel to the middle of the foot. The *metatarsus*, which consists of five long bones laid parallel to each other, and extending from the *tarsus* to the roots of the toes. The bones of the toes are called *phalanges*, from being in the form of a *phalanx*.

There are in all thirty-six bones in the foot; and the first question that naturally arises, is, why should there be so many bones? The answer is, In order that there may be so many joints; for the structure of a joint not only permits motion, but bestows elasticity.

A joint then consists of the union of two bones, of such a form as to permit the necessary motion: but they

* *Démonstration de l'Existence de Dieu, par Fénélon.*

are not in contact: each articulating surface is covered with cartilage, to prevent the jar which would result from the contact of the bones. This cartilage is elastic, and the celebrated Dr. Hunter discovered that the elasticity was in consequence of a number of filaments closely compacted, and extending from the surface of the bone, so that each filament is perpendicular to the pressure made upon it. The surface of the articulating cartilage is perfectly smooth, and is lubricated by a fluid called *synovia*, signifying a mucilage, a viscous or thick liquor. This is vulgarly called *joint-oil*, but it has no property of oil, although it is better calculated than any oil to lubricate the interior of the joint.

When inflammation comes upon a joint, this fluid is not supplied, and the joint is stiff, and the surfaces creak upon one another like a hinge without oil. A delicate membrane extends from bone to bone, confining this lubricating fluid, and forming the boundary of what is termed the cavity of the joint, although, in fact, there is no unoccupied space. External to this capsule* of the joint there are strong ligaments going from point to point of the bones, and so ordered as to bind them together without preventing their proper motions. From this description of a single joint, we can easily conceive what a spring or elasticity is given to the foot, where thirty-six bones are jointed together.

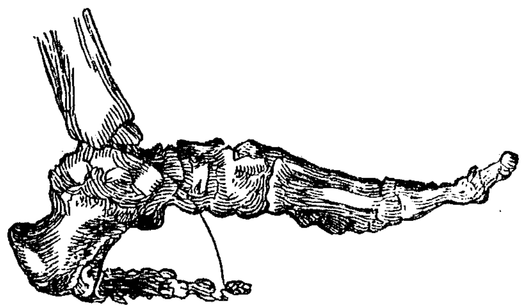
An elegant author has this very natural remark on the joints:—"In considering the joints, there is nothing, perhaps, which ought to move our gratitude more than the reflection, *how well they wear*. A limb shall swing upon its hinge, or play in its socket, many hundred times in an hour, for sixty years together, without diminution of its agility, which is a long time for anything to last, for anything so much worked and exercised as the joints are. This durability I should attribute, in part, to the provision which is made for the preventing of wear and tear: first, by the polish of cartilaginous surfaces; secondly, by the healing lubrication of the mucilage; and,

* From *capsula*, a little case, or box.

in part, to that astonishing property of animal constitutions, assimilation, by which, in every portion of the body, let it consist of what it will, substance is restored and waste repaired."—*Paley*.

If the ingenious author's mind had been professionally called to contemplate this subject, he would have found another explanation. There is no resemblance betwixt the provisions against the wear and tear of machinery and those for the preservation of a living part. As the structure of the parts is originally perfected by the action of the vessels, the function or operation of the part is made the stimulus to those vessels. The cuticle on the hands wears away like a glove; but the pressure stimulates the living surface to force successive layers of skin under that which is wearing, or, as the anatomists call it, desquamating; by which they mean, that the cuticle does not change at once, but comes off in *squamæ*, or scales. The teeth are subject to pressure in chewing or masticating, and they would, by this action, have been driven deeper in the jaw, and rendered useless, had there not been a provision against this mechanical effect. This provision is a disposition to grow, or rather to shoot out of their sockets; and this disposition to project, balances the pressure which they sustain; and when one tooth is lost, its opposite rises, and is in danger of being lost also, for want of that very opposition.

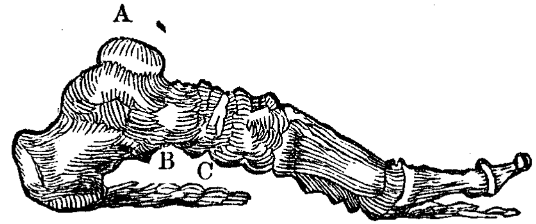
The most obvious proof of contrivance is the junction of the foot to the bones of the leg at the ankle joint. The two bones of the leg, called the *tibia* and the *fibula*, receive the great articulating bone of the foot (the *astragalus*) betwixt them. And the extremities of these bones of the leg project so as to form the outer and inner ankle. Now, when we step forward, and whilst the foot is raised, it rolls easily upon the ends of these bones, so that the toe may be directed according to the inequalities of the ground we are to tread upon; but when the foot is planted, and the body is carried forward perpendicularly over the foot, the joint of the leg and foot becomes fixed, and we have a steady base to rest upon. We next observe, that, in walking, the heel first touches the ground. If the bones of the leg were perpendicular over the part which first touches the ground, we should come down with a sudden jolt, instead of which we descend in a semicircle, the centre of which is the point of the heel.



And when the toes have come to the ground we are far from losing the advantages of the structure of the foot, since we stand upon an elastic arch, the hinder extremity of which is the heel, and the anterior the balls of the toes. A finely formed foot should be high in the instep. The walk of opera dancers is neither natural nor beautiful; but the surprising exercises which they perform give to the joints of the foot a freedom of motion almost like that of the hand. We have seen the dancers, in their morning exercises, stand for twenty minutes on the extremities of their toes, after which the effort is to bend the inner ankle down to the floor, in preparation for the Bolero step. By such unnatural postures and exercises the foot is made unfit for walking, as may be observed in any of the retired dancers and old *figurantes*. By standing so much upon the toes, the human foot is converted to something more resembling that of a quadruped, where the heel never reaches the ground, and where the paw is nothing more than the phalanges of the toes.

This arch of the foot, from the heel to the toe, has the astragalus (A) resembling the keystone of an arch; but, instead of being fixed, as in masonry, it plays freely

betwixt two bones, and from these two bones, B and C, a strong elastic ligament is extended, on which the bone (A) rests, sinking or rising as the weight of the body bears upon it, or is taken off, and this it is enabled to do by the action of the ligament which runs under it.

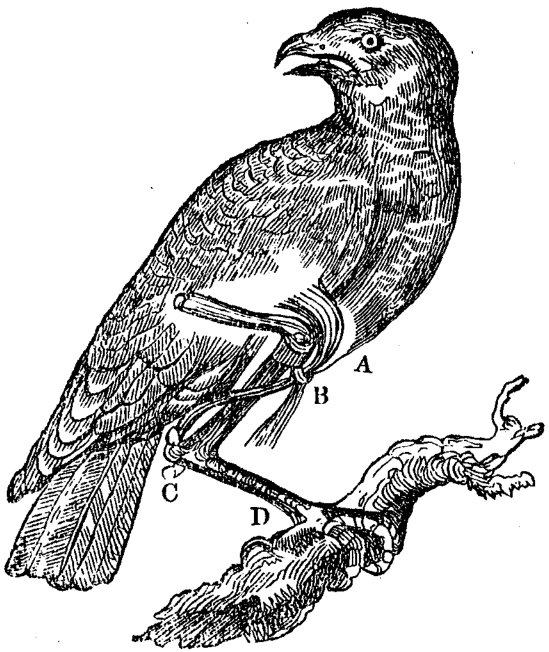


This is the same elastic ligament which runs extensively along the back of the horse's hind leg and foot, and gives the fine spring to it, but which is sometimes ruptured by the exertion of the animal in a leap, producing irrecoverable lameness.

Having understood that the arch of the foot is perfect from the heel to the toe, we have next to observe, that there is an arch from side to side; for when a transverse section is made of the bones of the foot, the exposed surface presents a perfect arch of wedges, regularly formed like the stones of an arch in masonry. If we look down upon the bones of the foot, we shall see that they form a complete circle horizontally, leaving a space in their centre. These bones thus form three different arches—forward, across, and horizontally: they are wedged together, and bound by ligaments, and this is what we alluded to when we said that the foundations of the Eddystone were not laid on a better principle; but our admiration is more excited in observing, that the bones of the foot are not only wedged together, like the courses of stone for resistance, but that solidity is combined with elasticity and lightness.

Notwithstanding the mobility of the foot in some positions, yet when the weight of the body bears directly over it, it becomes immoveable, and the bones of the leg must be fractured before the foot yields.

We shall proceed to explain how the knee-joint and hip-joint, independently of the exertion of muscles, become firm in the standing position, and when at rest: but, before we enter upon this, let us understand the much talked-of demonstration of Borelli, who explained the manner in which a bird sits upon a branch when asleep—the weight of the creature, and the consequent flexion of the limbs, drawing the tendons of the talons, so as to make them grasp the branch without muscular effort.



The muscle A passing over the joint at B, and then proceeding to the back of the leg, and behind the joint at C, and so descending behind the foot at D, it extends to the talons; and the weight of the bird, bending the joint B and C, produces the effect of muscular effort, and makes the claws cling.

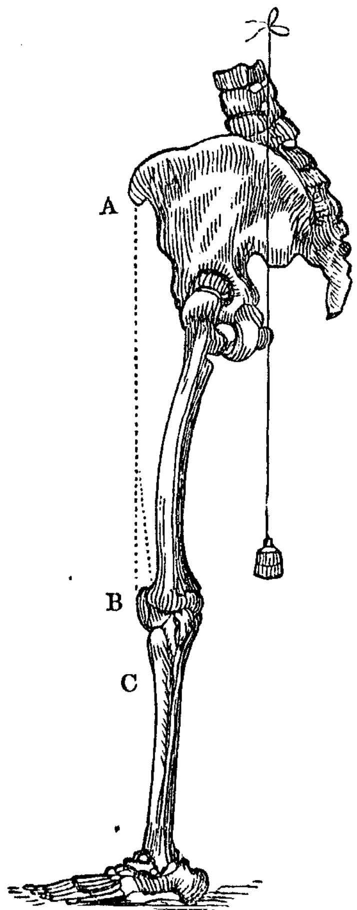
But why should the anatomist have recourse to this piece of comparative anatomy, when he has so fine an example in the human body? And one which is much more interesting, as, in fact, it is the foundation of

reasoning upon the diseases and accidents of the limb. If this beautiful arrangement in the healthy and perfect structure of a man's limb be not attended to, it would be easy to prove that many important circumstances, in regard to disease and accidents, must remain obscure.

The posture of a soldier under arms, when his heels are close together, and his knees straight, is a condition of painful restraint. Observe, then, the change in the body and limbs, when he is ordered to stand at ease; the firelock falls against his relaxed arms, the right knee is thrown out, and the tension of the ankle joint of the same leg is relieved, whilst he loses an inch and a half of his height, and sinks down upon his left hip. This command to "stand at ease" has a higher authority than the general orders. It is a natural relaxation of all the muscles; which are, consequently, relieved from a painful state of exertion: and the weight of the body bears so upon the lower extremity, as to support the joints independently of muscular effort. The advantage of this will be understood, when we consider that all muscular effort is made at the expense of a living power, which, if excessive, will exhaust and weary a man, whilst the position of rest which we are describing is without effort, and therefore gives perfect relief. And it is this which makes boys and girls, who are out of health and languid, lounge too much in the position of relief, from whence comes permanent distortion.

The following figure represents the bones of the leg.

The plumb-line shows the direction of the gravitation of the body falling behind the head of the thighbone. Now, if it be understood that the motions of the trunk are performed on the centre of the head of the thighbone, it must follow that the weight of the body in the direction of the plumb-line must raise the corner of the haunch-bone, at A. From this corner of the bone, a broad and strong band runs down to the knee-pan, B, in the direction of the dotted line. The powerful muscles which extend the leg are attached to the knee-pan, and through the ligament at C, operate on the bones of the leg, stretching them, and preventing the flexion of the



joint; but, in the absence of the activity of these muscles, the band reaching from A to B, drawn, as we have said, by the weight of the body, is equivalent to the exertion of the muscles, braces the knee-joint, and extends the leg; and we have before seen that the extension of the leg fixes the ankle-joint. Thus the limb is made a firm pillar under the weight of the body, without muscular effort.

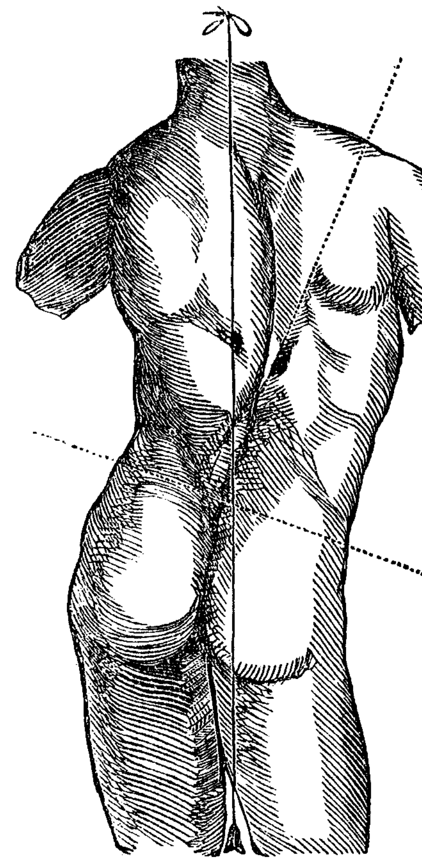
When the human figure is left to its natural attitudes, we see a variety and contrast in the position of the trunk and limbs.

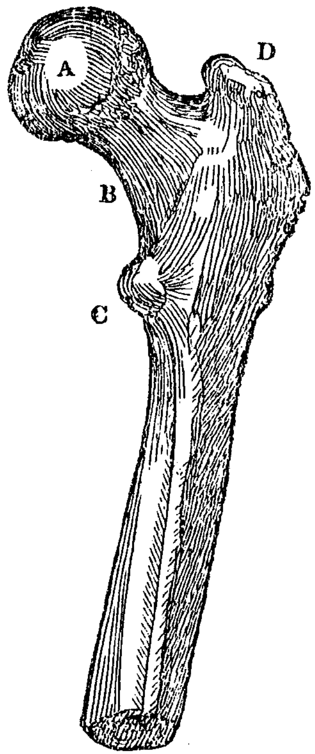
This position of the body resting on the lower extre-

mities throws the trunk into an elegant line, and places the limbs in beautiful contrast, as we see in all the best specimens of sculpture. (See below.)

Now that we have understood that the lower extremity becomes in some positions a firm pillar, it is the more necessary to observe the particular form of the head of the thigh-bone. (See next page.)

It is here seen that the head of the bone A stands off from the shaft by the whole length of the neck of the bone B; the effect of this is, that as the powerful muscles are attached to the knobs of bone C D, they turn the thigh-bone round in walking with much greater power than if the head of the bone were on a line with the shaft. They, in fact, acquire a lever power, by the



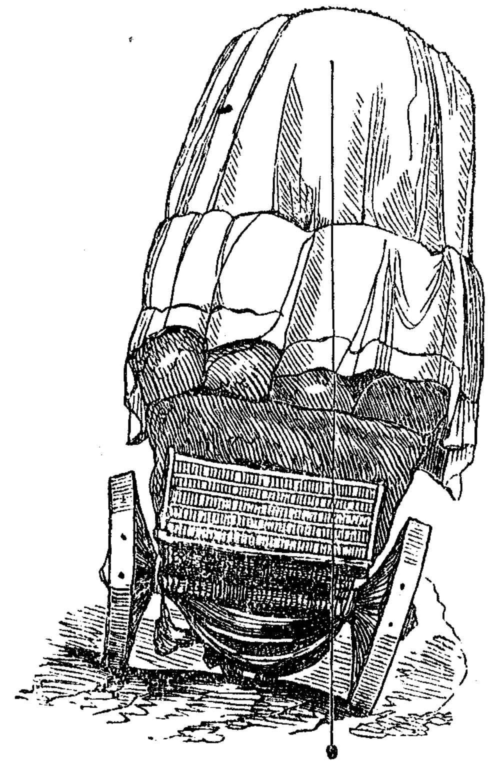


distance of D from A; as, during the action of these muscles, the limb is stiff, the rolling of the thigh directs the toe outwards in walking.

When the weight of the body is perpendicularly over the ball of the great toe, the whole body is twisted round on that point as on a pivot. This rolling of the body on the ball of the toe, and consequent turning out of the toes in stepping forward, is necessary to the freedom and elasticity of the motion. The form of all the bones of the leg, and the direction of all the muscles of the thigh and leg, combine to this effect. So far is it from being true, as painters affect to say, that the turning out of the toes is the result of the lessons of the dancing-master.

A certain squareness in the position of the feet is consistent with strength, as we see in the statues of the Herçules, &c.; but the lightness of a Mercury is indicated by the direction of the toes outwards. In women, there would be a defect from the breadth of the pelvis,

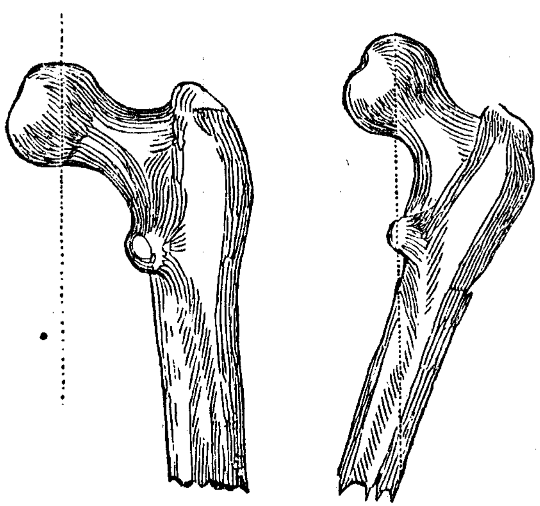
and a rolling and an awkward gait would be the consequence; but in them the foot is more turned out, and a light, elastic step balances the defect arising from the form of the pelvis. Any one may be convinced of this by observing people who walk awkwardly, especially if they walk unequally. Look at their feet, and you will see that one foot goes straight forward, whilst the other is turned outwards, and that when they come upon the straight foot, they come down awkwardly, and have no spring from it.



There is another curious circumstance in the form of the thigh-bone, showing how it is calculated for strength as well as freedom of motion. To understand it, we must first look to the *dishing* of a wheel—the dishing is the oblique position of the spokes from the nave to the felly, giving the wheel a slightly conical form. When a cart is in the middle of a road, the load bears equally upon both wheels, and both wheels stand with their spokes oblique to the line of gravitation.

If the cart is moving on the side of a barrel-shaped road, or if one wheel falls into a rut, the whole weight comes upon one wheel: but the spokes of that wheel, which were oblique to the load when it supported only one-half of the weight, are now perpendicular under the pressure, and are capable of sustaining the whole. If roads were made perfectly level, and had no holes in them, the wheels of carts might be made without dishing; but if a cart is calculated for a country road, let the wheelwright consider what equivalent he has to give for that very pretty result proceeding from the obliquity of the spokes, or *dishing* of the wheel.

When we return to consider the human thigh-bone, we see that the same principle holds; that is to say, that whilst a man stands on both his legs, the necks of the thigh-bones are oblique to the line of gravitation of the body; but when one foot is raised, the whole body then being balanced on one foot, a change takes place in the position of the thigh-bone, and the obliquity of that bone is diminished; or, in other words, now that it has the whole weight to sustain, it is perpendicular under it, and has therefore acquired greater strength. (See below.)



CHAPTER V.

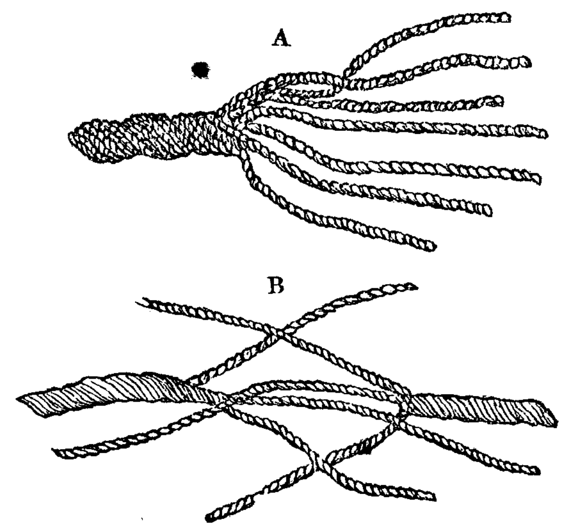
OF THE TENDONS COMPARED WITH CORDAGE.

WHERE nature has provided a perfect system of columns, and levers, and pullies, we may anticipate that the cords by which the force of the muscles is concentrated on the moveable bones must be constructed with as curious a provision for their offices. In this surmise we shall not be disappointed.

To understand what is necessary to the strength of a rope or cable we must learn what has been the object of the improvements and patents in this manufacture. The first process in rope-making, is hatchelling the hemp; that is, combing out the short fibres, and placing the long ones parallel to one another. The second is, spinning the hemp into yarns. And here the principle must be attended to, which goes through the whole process in forming a cable; which is that the fibres of the hemp shall bear an equal strain: and the difficulty may be easily conceived, since the twisting must derange the parallel position of the fibres. Each fibre, as it is twisted, ties the other fibres together, so as to form a continued line, and it bears at the same time a certain portion of the strain, and so each fibre alternately. The third step of the process is making the yarns. Warping the yarns, is stretching them to a certain length; and for the same reason that so much attention has been paid to the arrangement of the fibres for the yarns, the same care is taken in the management of the yarns for the strands. The fourth step of the process is to form the strands into ropes. The difficulty of the art has been to make them bear alike, especially in great cables, and this has been the object of patent machinery. The *hardening*, by twisting, is also an essential part of the process of rope-making; for without this, it would be little better than extended parallel fibres of hemp. In this twisting, first of the yarns, and then of the strands, those which are on the outer surface must be more stretched than those near the centre; consequently, when there is a strain upon the rope, the outer fibres will break first, and the others in succession. It is to avoid this, that each yarn and each strand, as it is twisted or hardened, shall be itself revolving, so that when drawn into the cable, the whole component parts may, as nearly as possible, resist the strain in an equal degree; but the process is not perfect, and this we must conclude from observing how different the construction of a tendon is from that of a rope. A tendon consists of a strong cord, apparently fibrous; but which, by the art of the anatomist, may be separated into lesser cords, and these, by maceration, can be shown to consist of cellular membrane, the common tissue that gives firmness to all the textures of the animal body. The peculiarity here results merely from its remarkable condensation. But the cords of which the larger tendon consists do not lie parallel to each other, nor are they simply twisted like the strands of a rope; they are, on the contrary, plaited or interwoven together.

If the strong tendon of the heel, or Achilles tendon, be taken as an example, on first inspection it appears to consist of parallel fibres, but by maceration these fibres are found to be a web of twisted cellular texture. If you take your handkerchief, and slightly twisting it, draw it out like a rope, it will seem to consist of parallel cords; such is, in fact, so far the structure of a tendon. But, as we have stated, there is something more admirable than this, for the tendon consists of subdivisions, which are like the strands of a rope; but instead of being twisted simply as by the process of hardening, they are plaited or interwoven in a way that could not be imitated in cordage by the turning of a wheel. Here then is the difference,—by the twisting of a rope, the strands cannot resist the strain equally, whilst we see

that this is provided for in the tendon by the regular interweaving of the yarn, if we may so express it, so that every fibre deviates from the parallel line in the same degree, and, consequently, receives the same strain when the tendon is pulled. If we seek for examples illustrative of this structure of the tendons, we must turn to the subject of ship-rigging, and see there how the seaman contrives, by undoing the strands and yarns of a rope, and twisting them anew, to make his splicing stronger than the original cordage. A sailor opens the ends of two ropes thus;* and places the strand of one



opposite and between the strand of another, and so interlaces them. And this explains why a hawser-rope, a sort of small cable, is spun of *three* strands; for as they are necessary for many operations in the rigging of a ship, they must be formed in a way that admits of being cut and spliced, for the separation of three strands, at least, is necessary for knotting, splicing, whipping, mail-

* A, Strands and Yarns opened.
B, Ends opened and laid for splicing, in a manner exactly like the interlacing of the tendon.

ing, &c., which are a few of the many curious contrivances for joining the ends of ropes, and for strengthening them by filling up the interstices to preserve them from being cut or frayed. As these methods of splicing and plaiting in the subdivisions of the rope make an intertexture stronger than the original rope, it is an additional demonstration, if any were wanted, to show the perfection of the cordage of an animal machine, since the tendons are so interwoven; and until the yarns of one strand be separated and interwoven with the yarns of another strand, and this done with regular exchange, the most approved patent ropes must be inferior to the corresponding part of the animal machinery.

A piece of cord of a new patent has been shown to us, which is said to be many times stronger than any other cord of the same diameter. It is so far upon the principle here stated, that the strands are plaited instead of being twisted; but the tendon has still its superiority, for the lesser yarns of each strand in it are interwoven with those of other strands. It, however, gratifies us to see, that the principle we draw from the animal body is here confirmed. It may be asked, do not the tendons of the human body sometimes break? They do; but in circumstances which only add to the interest of the subject. By the exercise of the tendons, (and their exercise is the act of being pulled upon by the muscles, or having a strain made on them,) they become firmer and stronger; but in the failure of muscular activity, they become less capable of resisting the tug made upon them, and if, after a long confinement, a man has some powerful excitement to muscular exertion, then the tendon breaks. An old gentleman, whose habits have been long staid and sedentary, and who is very guarded in his walk, is upon an annual festival tempted to join the young people in a dance; then he breaks his tendo Achillis. Or a sick person, long confined to bed, is, on rising, subject to a rupture or hernia, because the tendinous expansions guarding against protrusion of the internal parts have become weak from disuse.

Such circumstances remind us that we are speaking of

a living body, and that, in estimating the properties of the machinery, we ought not to forget the influence of life, and that the natural exercise of the parts, whether they be active or passive, is the stimulus to the circulation through them, and to their growth and perfection.

CHAPTER VI.

OF THE MUSCLES—OF MUSCULARITY AND ELASTICITY.

THERE are two powers of contraction in the animal frame—elasticity, which is common to living and dead matter, and the muscular power, which is a property of the living fibre.

The muscles are the only organs which properly have the power of contraction, for elasticity is never exerted but in consequence of some other power bending or stretching the elastic body. In the muscles, on the contrary, motion originates; there being no connexion, on mechanical principles, betwixt the exciting cause and the power brought into action.

The real power is in the muscles, while the safeguard against the excess of that power is in the elasticity of the parts. This is obvious in the limbs and general texture of the frame; but it is most perfectly exhibited in the organs of circulation. If the action of the heart impelled the blood against parts of solid texture, they would quickly yield. When, by accident, this does take place, even the solid bone is very soon destroyed. But the coats of the artery which receive the rush of blood from the heart, although thin, are limber and elastic; and by this elasticity or yielding they take off or subdue the shock of the heart's action, while no force is lost; for as the elastic artery has yielded to the sudden impulse of the heart, it contracts by elasticity in the interval of the heart's pulsation; and the blood continues to be propelled onward in the course of the circulation, without interval, though regularly accelerated by the pulse of the heart.

If a steam-engine were used to force water along the

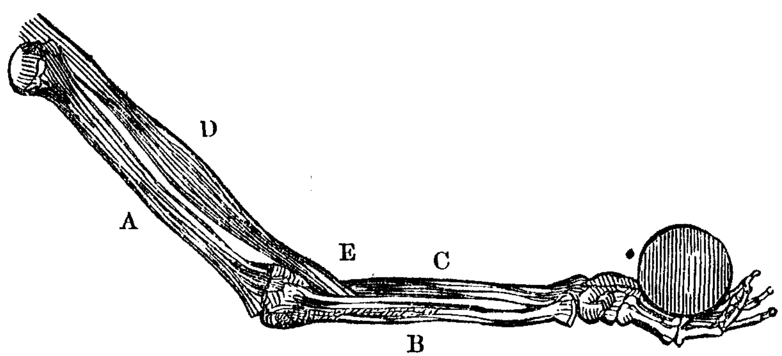
water-pipes, without the intervention of some elastic body, the water would not flow continuously, but in jerks, and, therefore, a reservoir is constructed containing air, into which the water is forced, against the elasticity of the air. Thus, each stroke of the piston is not perceptibly communicated to the conduit-pipe, because the intervals are supplied by the push of the compressed air. The office of the reservoir containing air is performed in the animal body by the elasticity of the coats of the arteries, by which means the blood which flows interruptedly into the arteries has a continuous and uninterrupted flow in the veins beyond them.

A muscle is fibrous, that is, it consists of minute threads bundled together, the extremities of which are connected with the tendons which have been described. Innumerable fibres are thus joined together to form one muscle, and every muscle is a distinct organ. Of these distinct muscles for the motions of the body there are not less than 436 in the human frame, independent of those which perform the internal vital motions. The contractile power which is in the living muscular fibre, presents appearances which, though familiar, are really the most surprising of all the properties of life. Many attempts have been made to explain this property, sometimes by chemical experiment, sometimes on mechanical principles, but always in a manner repugnant to common sense. We must be satisfied with saying, that it is an endowment, the cause of which it would be as vain to investigate as to resume the search into the cause of gravitation.

The ignorance of the cause of muscular contraction does not prevent us from studying the laws which regulate it, and under this head are included subjects of the highest interest; which, however, we must leave, to pursue the mechanical arrangement of the muscles.

Since we have seen that there are 436 distinct muscles in the body, it is due to our readers to explain how they are associated to effect that combination which is necessary to the motion of the limbs and to our perfect enjoyment. In the first place, the million of fibres, which constitute a single muscle, are connected by a tissue of nerves, which produce a union or sympathy amongst them, so that one impulse causes a simultaneous effort of all the fibres attached to the same tendon. When we have understood that the muscles are distinct organs of motion, we perceive that they must be classed and associated in order that many shall combine in one act; and that others, their opponents, shall be put in a state to relax, and offer no opposition to those which are active. These relations can only be established through *nerves*, which are the organs of communication with the brain, or sensorium. The nerves convey the will to the muscles, and at the same time they class and arrange them so as to make them consent to the motions of the body and limbs.

On first looking to the manner in which the muscles are fixed into the bones, and the course of their tendons, we observe everywhere the appearance of a sacrifice of mechanical power, the tendon being inserted into the bone in such a manner as to lose the advantage of the lever. This appears to be an imperfection, until we learn that there is an accumulation of vital power in the muscle in order to attain velocity of movement in the member.

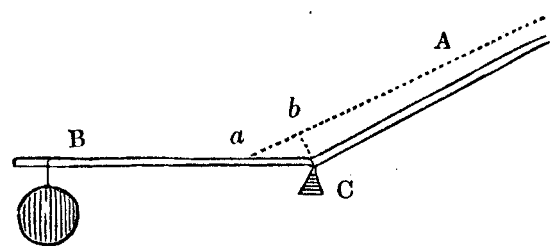


The muscle D, which bends the fore-arm, is inserted into the radius E, so near the fulcrum, or centre of motion in the elbow joint, and so oblique that it must

raise the hand and fore-arm with disadvantage. But, correctly speaking, the power of the muscle is not sacrificed, since it gains more than an equivalent in the rapid and lively motions of the hand and fingers, and since these rapid motions are necessary to us in a thousand familiar actions; and to attain this, the Creator has given sufficient vital power to the muscles to admit of the sacrifice of the mechanical or lever power, and so to provide for every degree and variety of motion which may answer to the capacities of the mind.

If we represent the bones and muscles of the fore-arm by this diagram, we shall see that power is lost by the inclination of the tendon to the lever, into which it is inserted. It represents the lever of the third kind, where the moving power operates on a point nearer the fulcrum than the weight to be moved.

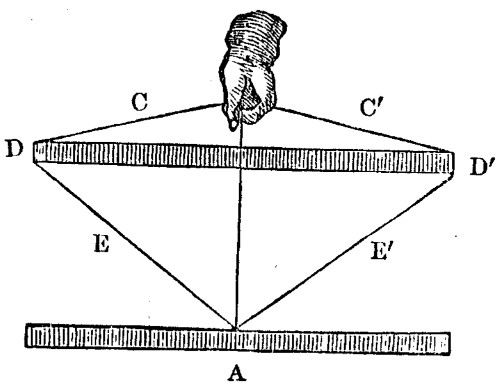
Here A represents the muscle, B the lever, and C the fulcrum. The power of the muscle is not represented by the distance of its insertion *a*, from the fulcrum C. The



line which truly represents the lever must pass from the centre of motion, perpendicularly to the line of the tendon, viz., C, *b*. Here, again, by the direction of the tendon, as well as by its actual attachment to the bone, power is lost and velocity gained.

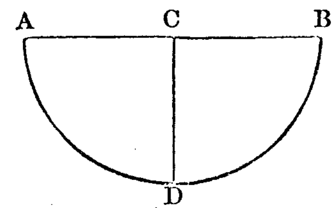
We may compare the muscular power to the weight which impels a machine. In studying machinery, it is manifest that weight and velocity are equivalent. The handle of the winch in a crane is a lever, and the space through which it moves, in comparison with the slow motion of the weight, is the measure of its power. If the weight, raised by the crane, be permitted to go down, the wheels revolve, and the handle moves with the velocity of a cannon-ball, and will be as destructive if it hit the workman. The weight here is the power, but it operates with so much disadvantage, that the hand upon the handle of the winch can stop it: but give it way, let the accelerated motion take place, and the hand would be shattered which touched it. Just so the fly-wheel, moving at first slowly, and an impediment to the working of a machine, at length acquires momentum, so as to concentrate the power of the machine, and enable it to cut bars of iron with a stroke.

The principle holds in the animal machinery. The elbow is bent with a certain loss of mechanical power; but by that very means, when the loss is supplied by the living muscular power, the hand descends through a greater space, moves quicker, with a velocity which enables us to strike or to cut. Without this acquired velocity, we could not drive a nail: the mere muscular power would be insufficient for many actions quite necessary to our existence.



Let us take some examples to show what objects are attained through the oblique direction of the fibres of the muscle, and we shall see that here, as well as by the mode of attachment of the entire muscle, velocity is attained by the sacrifice of power. Suppose these two pieces of wood to be drawn together by means of a cord, but that the hand which pulls, although possessing abundant strength, wants room to recede more than what is equal to one third of the space betwixt the pieces of wood; it is quite clear, that if the hand were to draw direct on the cord A, B, the point A would be brought towards B, through one third only of the intervening space, and the end would not be accomplished. But if the cord were put over the ends of the upper piece, C, D, E, and, consequently, directed obliquely to their attachment at A, on drawing the hand back a very little, but with more force, the lower piece of wood would be suddenly drawn up to the higher piece, and the object attained. Or we may put it in this form:—If a muscle be in the direction of its tendon, the motion of the extremity of the tendon will be the same with that of the muscle itself: but if the attachment of the muscle to the tendon be oblique, it will draw the tendon through a greater space; and if the direction of the muscle deviate so far from the line of the tendon as to be perpendicular to it, it will then be in a condition to draw the tendon through the greatest space with the least contraction of its own length.

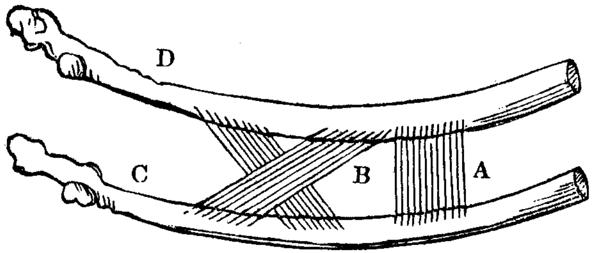
Thus, if A, B be a tendon, and C, D a muscle; by the contraction of C to D the extremities of the tendon A, B



will be brought together, through a space double the contraction of the muscle. It is the adjustment, on the same principle, which gives the arrow so quick an impulse from the spring of the bow, the extremities of the bow drawing obliquely on the string.

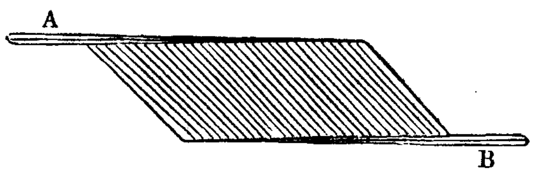
To free breathing, it is necessary that the ribs shall approach each other, and this is performed by certain *intercostal* muscles (or muscles playing between the ribs), and now we can answer the question, Why are the fibres of these muscles oblique?

Let us suppose this figure to represent two ribs with thin intervening muscles. If the fibres of the muscle were in the direction A, across, and perpendicular to the ribs;



and if they were to contract one-third of their length, they would not close the intervening space—they would not accomplish the purpose. But being oblique, as at B, although they contract no more than one-third of their length, they will bring the ribs C, D together. By this obliquity of the intercostal muscles, they are enabled to expand the chest in inspiration, in a manner which could not be otherwise accomplished.

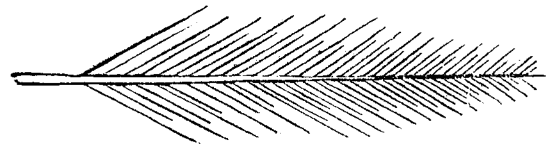
In the greater number of muscles the same principle directs the arrangement of the fibres; they exchange power for velocity of movement, by their obliquity. They do not go direct from origin to insertion, but obliquely, thus, from tendon to tendon:—



Supposing the point A to be the fixed point, these fibres draw the point B with less force, but through a larger space, or more quickly than if they took their course in direct lines; and by this aarrngement of the fibres the freedom and extent of motion in our limbs are secured.

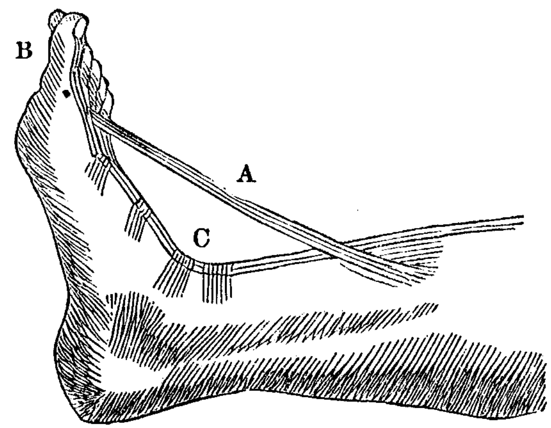
But the muscles must be strengthened by additional courses of fibres, because they are oblique; since by their obliquity they lose something of their force of action:

and therefore it is, we must presume, that we find them in a double row, making what is termed the *penniform* muscle, thus,—

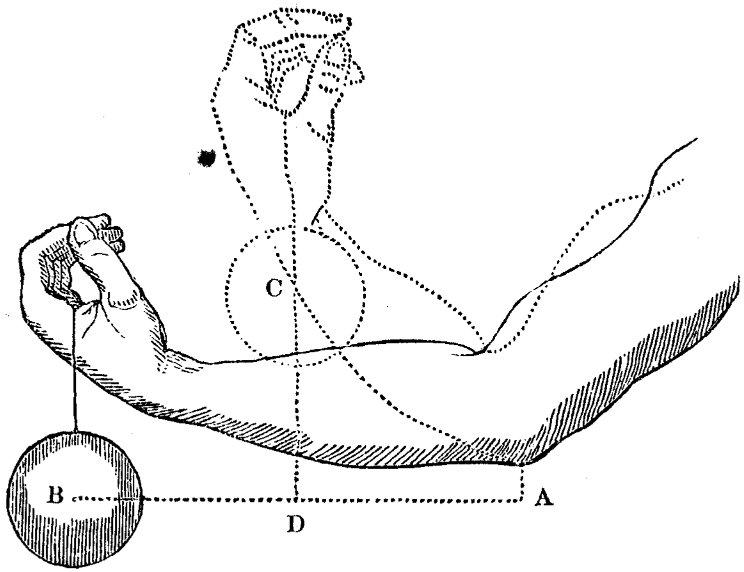


and sometimes the texture of the muscle is still further compounded by the intermixture of tendons, which permit additional series of fibres; and all this for the obvious purpose of accumulating power, which may be exchanged for velocity of movement.

We may perceive the same effect to result from the course of the tendons, and their confinement in sheaths, strengthened by cross-straps of ligament. If the tendon, A, took the shortest course to its termination at



B, it would draw up the toe with greater force; but then the toe would lose its velocity of movement. By taking the direction C, close to the joints, the velocity of motion is secured, and by this arrangement the toes possess their spring, and the fingers their lively movements. We may take this opportunity of noticing how the mechanical opposition is diminished as the living muscular power is exhausted. For example, in lifting a weight, the length of the lever of resistance will be from the centre of the elbow joint, A, to the centre of the weight, B. As the muscles of the arm contract, they lose something of their power; but in a greater proportion is the mechanical resistance diminished, for when the weight is raised to C A D, it becomes the measure of the lever of resistance.



A more admirable thing is witnessed by the anatomist—we mean the manner in which the lever, rising or falling, is carried beyond the sphere of action of one class of muscles, and enters the sphere of activity of others. And this adaptation of the organs of motion is finely adjusted to the mechanical resistance which may arise from the form or motion of the bones. In short, whether we contemplate the million of fibres which constitute one muscle, or the many muscles which combine to the movement of the limb, nothing is more surprising and admirable than the adjustment of their power so as to balance mechanical resistance, arising from the change of position of the levers.

In the animal body, there is a perfect relation preserved betwixt the parts of the same organ. The muscular fibres forming what is termed the belly of the muscle, and the tendon through which the muscle pulls, are two parts of one organ; and the condition of the tendon indicates the state of the muscle. Thus jockeys discover the qualities of a horse by its sinews or tendons. The most approved form in the leg of the hunter, or hackney, is that in which three convexities can be distinguished,—the bone; the prominence of the elastic ligament behind the bone; and behind that the flexor tendons, large, round, and strong. Strong tendons are provided for strong muscles, and the size of these indicates the muscular strength. Such muscles, being powerful flexors, cause high and round action, and such horses are safe to ride; their feet are generally preserved good, owing to the pressure they sustain from their high action. But this excellence in a horse will not make him a favourite at Newmarket. The circular motion cannot be the swiftest; a blood-horse carries his foot near the ground. The speed of a horse depends on the strength of his loins and hind quarter; and what is required in the fore-legs is strength of the extensor tendons, so that the feet may be well thrown out before, for if these tendons be not strong, the joints will be unable to sustain the weight of his body, when powerfully thrown forward, by the exertion of his hind-quarters, and he will be apt to come with his nose to the ground.

The whole apparatus of bones and joints being thus originally constituted by Nature in accurate relation to the muscular powers, we have next to observe, that this apparatus is preserved perfect by exercise. The tendons, the sheaths in which they run, the cross ligaments by which they are restrained, and the *bursæ mucosæ* * which are interposed to diminish friction, can be seen in perfection only when the animal machinery has been kept

* These *bursæ mucosæ* (mucous purses) are sacs containing a lubricating fluid. They are interposed wherever there is much pressure or friction, and answer all the purposes of friction-wheels in machinery.

in full activity. In inflammation, and pain, and necessary restraint, they become weak; and even confinement, and want of exercise, without disease, will produce imperfections. Exercise unfolds the muscular system, producing a full bold outline of the limbs, at the same time that the joints are knit, small, and clean. In the loins, thighs, and legs of a dancer we see the muscular system fully developed; and when we turn our attention to his puny and disproportioned arms, we acknowledge the cause—that, in the one instance, exercise has produced perfection, and that, in the other, the want of it has occasioned deformity. Look to the legs of a poor Irishman travelling to the harvest with bare feet: the thickness and roundness of the calf show that the foot and toes are free to permit the exercise of the muscles of the leg. Look, again, to the leg of our English peasant, whose foot and ankle are tightly laced in a shoe with a wooden sole, and you will perceive, from the manner in which he lifts his legs, that the play of the ankle, foot, and toes is lost, as much as if he went on stilts, and, therefore, are his legs small and shapeless.

And this brings us naturally to a subject of some interest at present: we mean the new fashion of exercising our youth in a manner which is to supersede dancing, fencing, boxing, rowing, and cricket, and the natural impulse of youth to activity.

By this fashion of training to what are termed *gymnastics*, children at school are to be urged to feats of strength and activity, not restrained by parental authority, nor left to their own sense of pleasurable exertion. They are made to climb, to throw their limbs over a bar, to press their foot close to their hip, their knees close to their stomach; to hang by the arms and raise the body, —to hang by the feet and knees,—to struggle against each other, by placing the soles of their feet in opposition, and to pull with their hands. No doubt, if such exercises be persevered in, the muscular powers will be strongly developed. But the first question to be considered is the safety of this practice. We have seen a professor of gymnastics, by such training, acquire great

strength and prominence of muscles; but by this unnatural increase of muscular power, through the exercises he recommended, he became ruptured on both sides. The same accident has happened to boys too suddenly put on these efforts.

It is proper to observe, that when the muscular power is thus, we may say, preternaturally increased, whether in the instance of a race-horse, an opera-dancer, or a pupil of the Calisthenic school, it is not merely necessary to put them on their exercises gradually in each successive lesson, but each day's exertion must be preceded by a wearisome preparation. In the great schools, like that at Stockholm, the master makes the boys walk in a circle; then run, at first gently; and so he gradually brings them into heat, and the textures of their frame are composed to that state of elasticity and equal resistance, as well as to vital energy, which is necessary for the safe display of the greater feats of strength and activity. This caution in the public exercises is the very demonstration of the dangers of the system. The boys will not be always under this severe control, and yet it is important to their safety.

We may learn how necessary it is to bring the animal system gradually into action from the effects of very moderate exercise on a horse just out of the dealer's hands. The purchaser thinks he may safely drive him ten miles, not aware that the horse has not moved a mile in a week, and the consequence is, inflammation and congestion in his lungs. The regulation in the army has been made on a knowledge of these facts. When young horses are brought from the dealer they are ordered to be walked an hour a-day the first week, two hours a-day the second week, three hours a-day in the third week. They are to be fatigued by walking, but they must not be sweated in their exercise. Horses for the turf, under three years old, in training for the Derby, are brought very slowly to their exercise, beginning with the lounge; then a very light weight is put upon them, and that gradually increased. Indeed, nothing can better show the effects of exercise in perfecting the muscular action than the consequence of the loss of one day's training. It will bring the favourite to the bottom of the list, and that without any suspicion of lameness, but from a knowledge of the fact, that even such a slight irregularity in his training will have a sensible effect on his speed. Shall the possibility of pecuniary loss excite the jockey to more care for his horse than we, in our rational and humane attention to the education of our youth, pay to their health and safety?

In reflecting on these many proofs of design in the animal body, it must excite our surprise that anatomy is so little cultivated by men of science. We crowd to see a piece of machinery or a new engine, but neglect to raise the covering which would display in the body the most striking proofs of design, surpassing all art in simplicity and effectiveness, and without any thing useless or superfluous.

A more important deduction from the view of the animal structure is, that our conceptions of the perfection and beauty in the design of nature are exactly in proportion to the extent of our capacity. We are familiar with the mechanical powers, and we recognise the principles in the structure of the animal machine; and in proportion as we understand the principles of hydrostatics and hydraulics, are able to discern the most beautiful adaptation of them in the vessels of an animal body. But when, to our further progress in anatomy, it is necessary that we should study a matter so difficult as the theory of life, imperfect principles or wrong conceptions distort and obscure the appearances: false and presumptuous theories are formed, or we are thrown back in disappointment into scepticism, as if chance only could produce that, of which we do not comprehend the perfect arrangement. But studies better directed, and prosecuted in a better spirit, prove that the human body, though deprived of what gave it sense and motion, is still a plan drawn in perfect wisdom.

A man possessed of that humility which is akin to true

knowledge, may be depressed by too extensive a survey of the frame of nature. The stupendous changes which the geologist surveys — the incomprehensible magnitude of the heavenly bodies moving in infinite space, bring down his thoughts to a painful sense of his own littleness: "to him the earth with men upon it will not seem much other than an ant-hill, where some ants carry corn, and some carry their young, and some go empty, and all to and fro—a little heap of dust." *

He is afraid to think himself an object of Divine care; but when he regards the structure of his own body, he learns to consider space and magnitude as nothing to a Creator. He finds that the living being, which he was about to contemn, in comparison with the great system of the universe, exists by the continuance of a power, no less admirable than that which rules the heavenly bodies; he sees that there is a revolution, a circle of motions no less wonderful in his own frame, in the microcosm of man's body than in the planetary system; that there is not a globule of blood which circulates, but possesses attraction as incomprehensible and wonderful as that which retains the planets in their orbits.

The economy of the animal body, as the economy of the universe, is sufficiently known to us to compel us to acknowledge an Almighty power in the creation. What would be the consequence of a further insight—whether it would conduce to our peace or happiness—whether it would assist us in our duties, or divert us from the performance of them, is very uncertain.

* Bacon.

PART II.

SHOWING THE APPLICATION OF THE LIVING FORCES.

Amongst the least informed people, and in remote villages, there are old saws and rules regarding health, sickness, and wounds, which might be thought to come from mere experience; but they are, on the contrary, for the most part, the remains of forgotten theories and opinions, laid down by the learned of former days. Portions of knowledge, it would appear, confined at first to a select part of society, are, in the progress of time, diffused generally, and may be recognised in the aphorisms of the poor. These are traced to their source only by the curious few, who like to read old books, and to observe how that which is originally right, becomes, through prejudice and ignorance, distorted and fantastical.

If a very little exact knowledge of the structure of our own frames were more generally diffused, charity would be advanced, empirics could hardly maintain their influence, and medical men might have a farther motive to desire professional eminence.

Men suppose that the knowledge of their own bodies must be a science locked up from them, because of the language in which it is conveyed; or they take away their thoughts from it, as from the contemplation of danger, unwilling to survey the slight ties by which they hold their lives. They are like persons for the first time at sea, who shudder to calculate how many circumstances must concur to speed the frail vessel on its voyage, and how little is between them and the deep. It is then a mean and timid spirit that shuts out from our contemplation the finest proofs of Divine Providence. Galen's treatise on the uses of the parts of the human body

was composed as a hymn to the Creator, and abounds in demonstrations of a Supreme Cause; and when Cicero desires to prove the existence of the Deity from the order and beauty of the universe, he surveys the body of man, deeming nothing more godlike, as marking man's superiority to the brutes, than the privilege of contemplating his own condition, since it teaches him the ways of Providence, from a knowledge of which come piety and all the virtues.

Although we are writing under the title of Animal Mechanics, the reader must be aware that we cannot proceed much farther, on mechanical principles alone. At least, before we have it in our power to illustrate particular parts of the animal frame, by reference to those principles, we must have the proofs before us that we are considering a living body. It is the principle of *life* which distinguishes the studies of the physiologist from the other branches of natural knowledge. To lose sight of this distinction is to tread back the path, and to engage once more in the vain endeavour to explain the phenomena of life on mechanical principles. We have taken mechanics in their application to mechanical structure in the living body, because they give obvious proofs of design, and in a manner that admits of no cavil. Yet, although those proofs are very clear in themselves, they are not so well calculated to warm and exalt our sentiments as these which we have now to offer in taking a wider view of the animal economy.

In entering on the second department of this treatise, the reader may be startled at the subjects of discussion; but this comes also from ignorance of their nature. Much may be learned from the observation of things familiar. Their perpetual recurrence banishes reflection respecting them, but it is the business of philosophy to make us alive to the importance of that which we have been accustomed to from childhood, and have, therefore, long ceased to observe with attention.

In the first chapter of this second part we shall continue to examine the operations of the animal body, independently of the agency of the living property. We shall consider it as a mere hydraulic machine. Following the blood in its circle through cisterns and conduit pipes, we shall point out the application of the principles of this science as we formerly did those of mechanics, and so arrive at the like conclusions by a different course. And as we before found every muscular fibre adjusted with mechanical precision, so now we shall find every branch of an artery, or of a vein, taking that precise course and direction which the experience of the engineer shows to be necessary in laying the pipes of an engine.

Having thus surveyed the mechanical operations of the animal body, and the course of the fluids conveyed through it, on hydraulic principles, we shall consider ourselves as having advanced through the meaner to the higher objects of inquiry, and proceed to show how the principle of life bestows different endowments on the framework; how motion originates in a manner quite different from that produced by mechanical forces; how the sensibilities animate the living properties of action; how the different endowments of life correspond with each other, and exhibit power and design in a degree far superior to any thing that we observed in the mechanical adjustment of the parts, or the circulation of the fluids.

CHAPTER I.

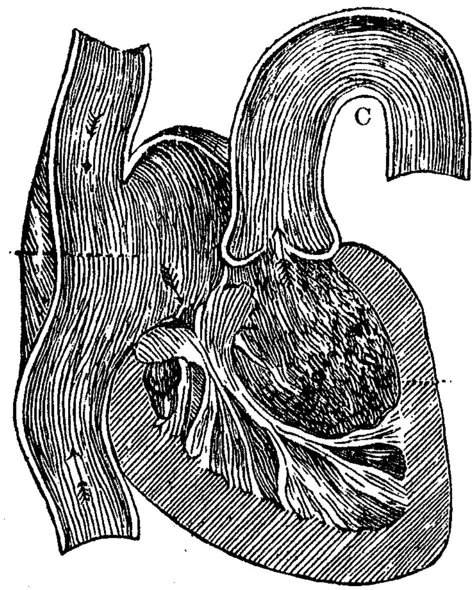
THE CIRCULATION OF THE BLOOD, UPON THE PRINCIPLES OF HYDRAULICS.

In tracing the course of the circulation of the blood, it is natural to inquire how far the system of reservoirs, pipes, and valves, which form the apparatus for conveying it, are constructed on the principles of hydraulics.

We find this difficulty in the outset, that the vessels containing the blood are not rigid, like those the engineer employs in erecting hydraulic machinery. Instead of resembling pipes which convey water, and which receive the force of gravitation on them, they have both elasticity and an appropriate living power. The artery, the tube which conveys the blood out from the heart to the body, has a property of action in itself. Its elasticity and muscular power must derange those influences which we study in pure hydraulics.

There is to be found, notwithstanding, a great deal that is common to both, when we compare the tubes of an animal body with the hydraulic engine; the capacity of the vessels; the increase, or diminution, of their calibres; their curves; the direction of their branches; —all these ought still to be on the same principles on which experience has taught men to form conduit pipes. We ought not to be indifferent to these proofs of design, because we acknowledge that an infinitely superior power is brought into operation in the animal body, and which is necessary to the circulation of the blood. It renders the inquiry more difficult, but it does not obscure the inferences drawn from the consideration of the whole subject.

We shall first present to our readers the simplest form of the Heart. It is not necessary to detail the more complicated structure of the human heart, where, in fact, two hearts are combined; the fibres of the one continued into the fibres of the other, and the tubes twisting round one another so as to present the form which is familiar to everybody. Although there are four intricate cavities, seven tubes conveying the blood into them, and two conveying it out of them, we shall, for the purpose of considering the forces circulating the blood, and comparing the living vessels with pipes, present the heart and vessels as simple; yet, with perfect truth, being, in fact, the heart and vessels of animals of more simple structure.



The action of the heart is this: the blood returns from the body by veins into the sinus or auricle,* A, and distends it: this sinus is surrounded with muscular fibres; by the distention or elongation of these fibres they are excited,

* Auricle, from *auricula*, the flap of the ear, is a name given to the sinus, because a corner of it hangs over like a dog's ear.

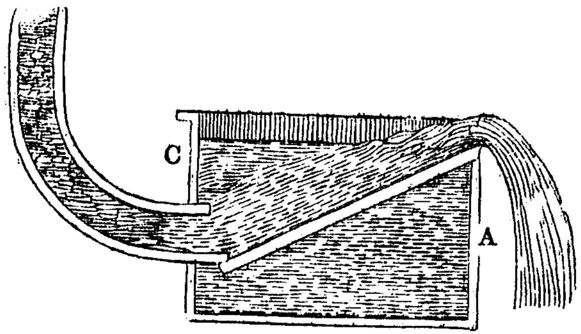
and the sinus contracts and propels the blood into the ventricle, B. The ventricle is more muscular; it is, in fact, a powerful hollow muscle; it is excited by the distention, and contracts and propels the blood into the artery, C.

We understand then that every heart must, at least, consist of two cavities alternating in their action; that the vessel which carries the blood to them is called a vein; and that the vessel which carries the blood out from them is the artery.

The first thing that strikes a person examining the heart is the extraordinary intricacy of the cavities, from the interlacing of its muscular fibres, and he naturally says that they appear ill calculated for conveying a fluid through them. There is an attraction between fluids and solids, he might observe, and this attraction is increased by the extension of the surfaces of the pillars and cords which he sees in the interior of the heart.

We must remind him that the blood is coming back from the body, having performed very different offices in different parts, and has parted with different properties in the several organs it has supplied. There is in that stream of blood which enters through the vein a new supply of fluid which has come by digestion, the material for making fresh blood, as well as that which has run the circle. These two fluids must be thoroughly mixed together, and, no doubt, this is one of the offices provided for by the intricacy of the interior of the heart.

Again, looking to the recesses of the cavities formed between the fleshy columns, and behind the valves, we might suppose that the blood would remain there stagnant. There are cavities or recesses too in the remote parts of the circulating vessels, where we might suspect that the influence of the stream would not be felt, and a stagnation might take place. But there is attraction between the particles of fluids as well as between the fluids and their containing tubes. Let us see then how, in this figure, a stream of water carried through a cistern of water will, by its friction, draw after it the water in the cistern, and carry it above its natural level, and over the side of the vessel.



The stream entering the reservoir, A, by the pipe, B, carries with it all the water, C, which stands above the level of its upper surface. By this we see that the stream of blood entering into the heart, even if its cavities were not emptied at each pulse, as some contend they are, would draw out the blood from its recesses, so that no part could remain stagnant, but, on the contrary, all would be carried in eddies round the irregularities until they took the direction of the great artery, in which they would be perfectly combined.

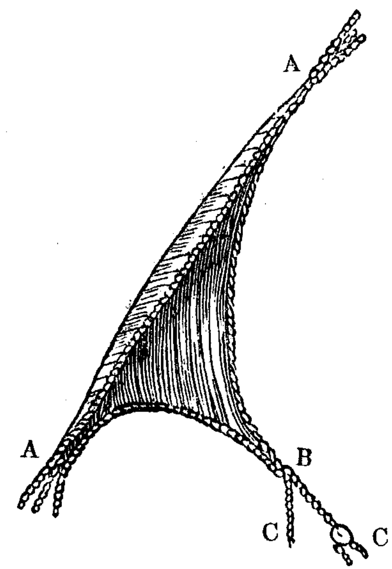
The next thing to be noticed partakes of the nature of a mechanical provision—we mean the action of the valves.

We must here remark, that the opening into the ventricle is very different from that which leads out of it—the latter being much smaller. Medical writers describe this as if it were nothing to them, and a mere accident. But it must be recollected, that a stream of water entering a reservoir, is in a very different condition from that which is going out of it; it is on this principle that the mouths (*ostia* is the anatomical term) of the ventricle are differently formed, and it is this difference which makes the structure of the valves which guard those passages so dissimilar and so appropriate. Without attention to this, we should follow our medical authorities, and call this variety in the mechanical adaptation a mere playfulness

in nature. It is more agreeable to us, to see a precision of design visible at the first step of this inquiry.

The valves of the heart are regular flood-gates which close the openings against the retrograde motions of the blood. They are not all of the same mechanical construction; and their difference deserves the reader's attention as proving design in this hydraulic machinery.

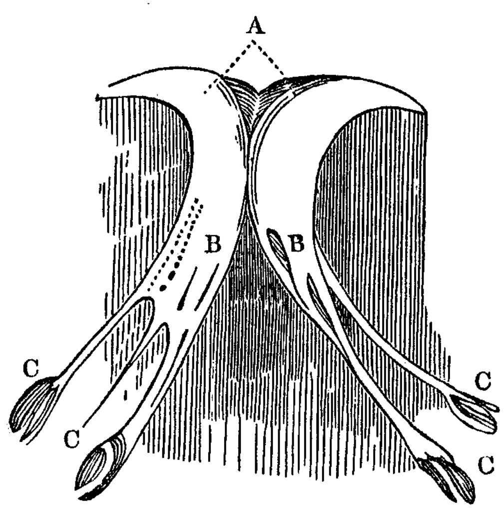
The valve which we have first to describe closes the opening betwixt the auricle or sinus and the ventricle, and prevents the action of the ventricle propelling the blood back again into the auricle.



It is a web or membrane, resembling a sail, when bagged by the wind. The blood catches the margin of this membrane, and distends it as the wind does the stay-sail, or jib, of a vessel, which it much resembles, being triangular and pointed. There are three of these membranes, and the valve is called *tricuspid*, or three-pointed. Three membranes then, of this kind, combining and being floated back upon the mouth of the opening, effectually close it.

The illustration of the action of these valves by a sail is so perfect, that if the reader will have patience to attend to those little contrivances which the mariner finds necessary for strengthening his canvass, and giving to it the full influence of the wind, he will have an accurate idea of the adjustment of these floating valves.

To carry on the comparison—one edge of the stay-sail is extended upon the stay A A, and tied to it by *hanks*. The edges of the sails called the *leeches* have a *bolt-rope* run along them; and on the edge where it is attached the canvass is strengthened by being hemmed down or tabled. In the same way as the foot of the sail, or lower margin, is strengthened with the bolt-rope, just so are the valves strengthened at their edges and their corners. Where the two ropes join in the loose corner of the sail, they form a clue—a loop to which tackle is attached; the valve has such a corner, so strengthened, and has a cord attached. The corners of the sail are strengthened by additional portions of canvass called patches; so are the valves strengthened where their tendons are infixed. To the corner or clue, B, ropes are attached which are called the *sheets*, C C. These being drawn tight, spread out the foot of the sail to one side or the other, according to the direction of the wind, and the tack the ship is on; the valves have also their tackle; and, in short, we shall find a resemblance to all the parts of a sail in the valves of the heart.



One edge of the triangular valve is tied to the margin of the opening, as one of the leeches of the sail is attached to the stay; the opposite corner is loose, and floats, as the sail does in tacking, until the blood, bearing against it as the wind bears against the sail, bags and distends it; the corner is then held down by tendons, for there are cords attached to the corner of the valve, as well as to the corner of the sail. These the anatomist calls *cordæ tendineæ*, B B, which in their office have an exact resemblance to the ropes called the sheets of the sail. They are delicate tendons attached to the margin of the valve, and they prevent the margin from being carried back into the auricle.

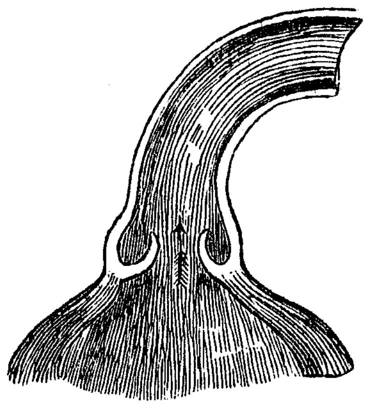
Here we find a very beautiful muscular apparatus which is necessary to the perfect adjustment of these cords. The cords are attached to small muscles called *columnæ carneæ*, C C, or fleshy columns, which at their other extremities are incorporated with the muscular wall of the ventricle itself. The use of these muscles is now to be explained. Had the tendinous cords of the valves been tied to the inside of the wall of the ventricle, without the intervention of these muscles, as the walls of the cavity approach each other during their contraction, the tendinous cords would have been let loose, and the margins of the valves carried back into the auricle. But by the intervention of these muscles, they are pulled upon and shortened in proportion as the sides of the cavity approach each other.

On the whole, then, we perceive that this apparatus, which is as intricate as the rigging of a ship, consists of a variety of fleshy columns and cords, many of which, in fact, run across the cavity of the ventricle.

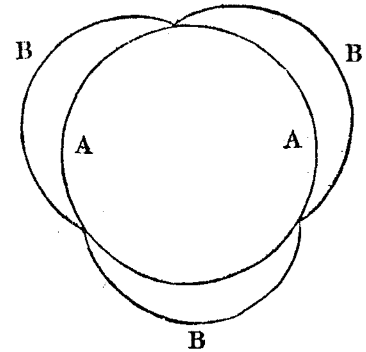
We are about to exhibit another form of a valve, much simpler, and yet we are bound to believe equally effectual: which tends to support the opinion expressed above, that besides preventing the retrograde motion of the blood, this intricate apparatus of the ventricle is intended more effectually to agitate and to mix the different streams.

At the root or origin of the great artery, called the

Aorta, there is a firm ring to which the valves now to be described are attached. The necessity of this will appear evident, since, if the ring could be stretched by the force of the heart's action, the valves or flood-gates would not be sufficient to close the passage; their conjoined diameters would not equal that of the artery which they have to close. These valves are three in number: they are little half-moon-shaped bags of thin membrane, which are thrown up by the blood passing out from the ventricle, but by the slightest retrograde movement of the blood their margins are caught, and then, being distended or bagged, they fall together, and close the passage. There are some curious little adjuncts to these valves, which ought to be explained, as showing the accuracy of the mechanical provision.

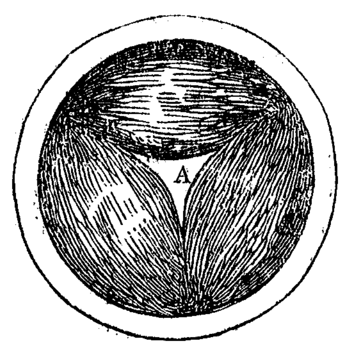


When the margin of the valve is thrown up by the blood passing out of the heart, it is not permitted to touch or fall flat upon the side of the artery, for if it did, it would not be readily caught up by the blood that flows back; there is therefore a little dilatation of the coats of the artery behind each valve by which, although the margins of the valve be distended to the full circle, they never cling to the coats. These valves, then, are never permitted to fall against the coats of the artery, and therefore they are always prepared to receive the motion of the refluent blood.

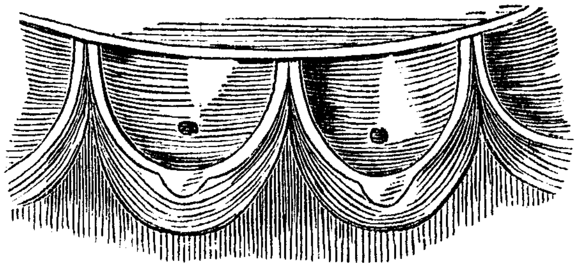


Let this figure represent a transverse section of the root of the aorta, A A, the inner circle is the margin of the three valves thrown up to let the blood pass. B B B are three semicircular bags formed by the dilatation of the coats of the artery at this part, receding from the margin of each of the valves—consequently, in such a manner as to leave a space between the valves and the sides of the vessel.

To strengthen the valves, a tendon runs along their margin like the bolt-rope or foot-rope along the edge of a sail, and these ligaments are attached to the side of the artery, and give the valve great strength.



These valves, we have said, are semilunar; consequently, when they fall together, there must be a space, A, left between them. If we put the points of the thumb, fore and middle fingers, together, there is a triangular space left between them; such a space between the convexities of the three valves would be a defect.



The artery open, and the semi-lunar valves, like little bags, attached to the inside.

Three little bodies like tongues are therefore attached to the middle of the margin of each valve, and these falling together, when the valve is shut down, perfect the septum and prevent a drop of blood passing backwards.

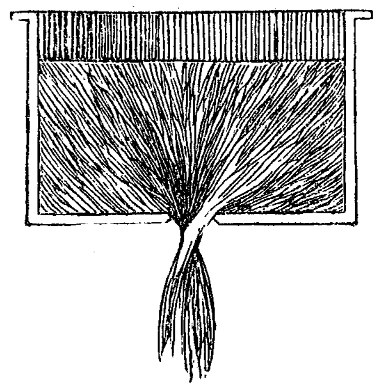
The valves have no power of accelerating the motion of the blood; they only prevent its retrograde motion, and cause the whole power of the heart to be employed in directing the blood forwards in the course of the circulation. But when they are ruptured, when the valve first described is rent, or the cordæ tendineæ are broken, then the membrane, which we have said is like a sail, is carried back from the second into the first cavity. It is like the sail torn from the sheets and flying out before the wind: the effect is terrible: the pulse of the heart, the whole force of which should be given to carry the blood forwards in the arteries, has half its force directed backwards upon the veins.

In the same manner the semilunar valves in the root of the aorta may have their margins torn. We have described the margin of these valves to be strengthened by a tendon or cord run along their edge, like the rope which is sewed to the edge of a sail. There is an obvious intention in strengthening the valve here; but when textures of this kind become impaired in the human frame, this may give way and be torn, and then

the reaction of the artery, when the heart has given its stroke, is lost; for, instead of impelling the blood forwards, the blood runs backwards into the heart. The effect of these accidents is extreme debility of circulation, with symptoms varied according as the defect falls on the circulation through the lungs or through the body—that is, whether on the right or the left heart of man. But such accidents are rare, and never take place until disease has impaired he strength of what we may call the tackle of the valve.

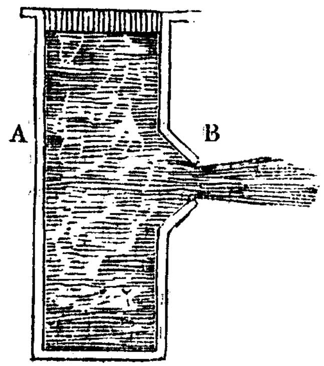
The next remark is founded more directly on the hydraulic principle.

This ring and these valves at the beginning of the great artery imply a certain constriction, or diminution of the tube at this part; and we have now to show that such a contraction of the tube at this precise part does not diminish the diameter of the column of blood. This appears an inconsistency; but if a stream of water flow from a cistern, through a hole in that cistern, the column of water will be diminished at a certain point of its exit.



The water flowing through the bottom of the cistern may be represented by converging lines; and their united forces impelling the stream forward, contract it just beyond the exit—the *Vena Contracta*. Nature, taking advantage of this law, has constructed the narrow ring which we have shown is necessary to the accurate adjustment of the valve, at the precise part where the blood, issuing from the cavity of the ventricle, is necessarily contracted to the smallest space. The column of blood would be contracted at this point, even if there were no coats of the artery to confine it there.

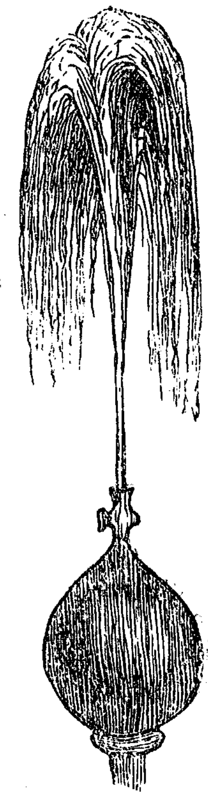
We had thought of this as a thing indicated by reasoning, but we find that an appropriate experiment has been made which proves it.



A being the side of a reservoir, and B a short tube giving issue to the water, it will deliver as much water by this conical constructed mouth, as if the tube were of equal diameter with the hole in the reservoir. The reader will perceive how satisfactorily this indicates what is designed by the difference in the size of the mouth of the ventricle which gives entrance, and that which gives issue to the blood.

With a view to explain the motion of fluids in tubes, and finally the motion of the blood in the blood-vessels, let us consider what takes place in the motion of the column of water which is not contained in a tube.

When water is poured out, and descends in an uninterrupted stream, the column contracts as it descends, until it has acquired such a velocity, that the atmosphere opposes it and scatters it; we do not mean the contraction illustrated by the figure in p. 239, but that gradual diminution of the diameter of the stream, owing to the height from which it falls. We apprehend that this is on the principle,

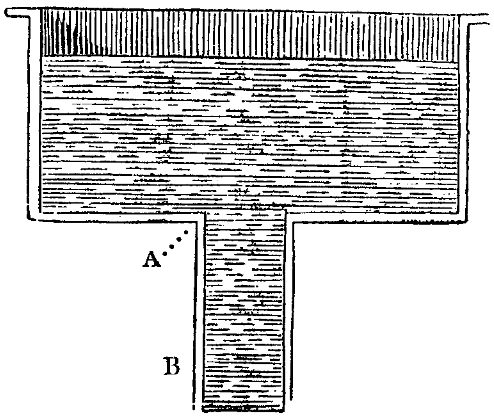


that falling bodies are accelerated as the square root of the height from which they fall. The stream being more rapid at its lower part, is necessarily smaller in diameter, until, having acquired considerable velocity, the resistance of the atmosphere separates its filaments, and it becomes broader again.

A very different appearance is presented in a jet d'eau; here the ascending stream widens as it ascends. The explanation of this we conceive to be, that the fluid is retarded as it mounts, and that the stream propelled from below is forced between the filaments* of the

* Those who treat of hydraulics divide a column of water into ideal lesser columns, which they call filaments, with a very different meaning from the fibres of the anatomist.

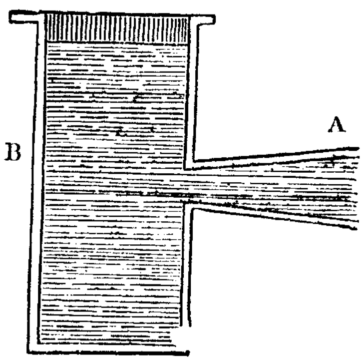
column above, and disperses them, so as to give the column a conical form.



This reservoir will be emptied more rapidly if, instead of a hole in the bottom at A, the water be discharged by a tube, A B, of the diameter of the hole.—Here the column of water being perpendicular, it will be accelerated at its lower part; but instead of diminishing its diameter, as it would do, if not confined by a tube, it will draw an additional volume of water down, and accelerate the discharge.

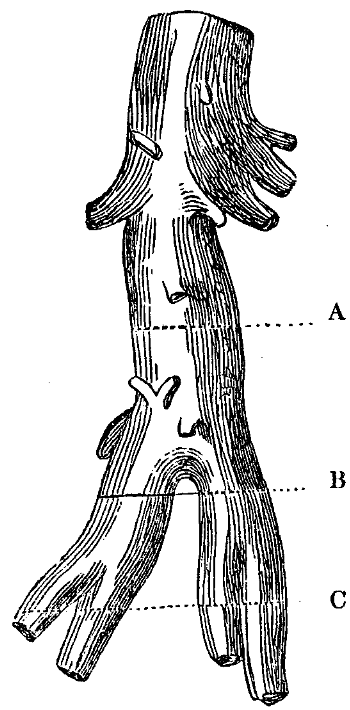
It will be very different if the force be altogether from behind, as when water is propelled into a horizontal tube.

The tube A being conical, will discharge more fluid from the reservoir B than if it had been of equal length,



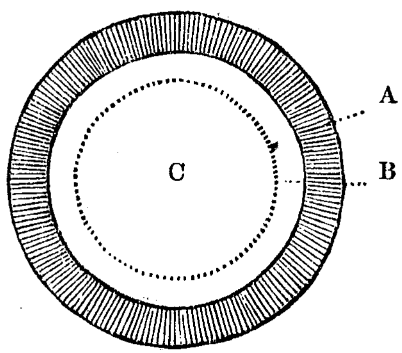
and its diameter throughout the same as at its commencement. Because, as it appears to us, the weight of the descending column being the force, and this operating as a *vis a tergo*, it is like the water propelled from the jet d'eau, and the gradual expansion of the tube permits the stream from behind to force itself between the filaments, and disperses them without producing that pressure on the sides of the tube which must take place where it is of uniform calibre. These principles will give great interest to the following fact.

The celebrated John Hunter took great pains to prove that the artery had its diameter enlarged as it proceeded from the heart, and that the areas of the branches of an artery were greater than the diameter of the parent trunk.



That is to say, the section of the trunk at A was not so great as the two sections at B, taken together; that the two sections at B taken together, were not so great as the four sections at c; that the conjoined diameters, therefore, of the branches of an artery were greater than the diameters of the artery itself. This fact has been sometimes expressed by saying that the artery was a cone with its apex in the heart.

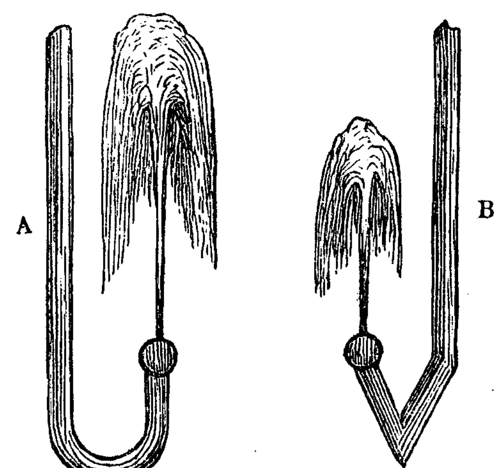
When we stand by a rapid river, we can perceive that the surface of it is not level. The stream is rapid in the middle, and there the water is highest. The friction of the water against the bottom and the sides retards the stream, whilst the greater velocity of the current in the centre draws the water to it, which is the reason of its elevation there.



For the same reason, if an engineer estimate the quantity of fluid to be delivered through a tube without estimating the friction of the sides, he will be disappointed in the result of his calculation; for, as the water of the river is delayed by the bottom and sides, so is the fluid in the tube retarded by the attraction or friction between the water and the tube. And, if we can imagine a section representing the tube and the flowing water, A will be the solid tube, B the water retarded or arrested by the friction against the tube, and the space C, within the inner circle, would represent that part of the stream which is in uninterrupted flow. The engineer will therefore lay a tube larger than would be necessary, were there neither attraction nor friction between the solid and fluid. It must further appear that the smaller the calibre of the tube, the surface of attraction or friction will be propor-

tionally greater. Does not this explain the anatomical fact which we have been contemplating, that the area of the smaller branches is comparatively larger than the trunk from which they are derived?

Two beneficial effects result from this; for we must observe that the blood-vessels of the body are reservoirs as well as conduit pipes. A man of middling stature has thirty-three pounds of blood in his circulating vessels: if the vessels did not enlarge as they receded from the heart, there would be no place for the deposit of this great quantity of blood. The advantages, then, of this particular form are, first, that a quantity of blood necessary to the economy is contained within the vessels; and, secondly, that the blood is more easily urged forwards by the action of the heart. The reader will not now be surprised in learning that a pipe of a conical form, that is, enlarging as it proceeds, gives the least interruption to the flow of water from a reservoir.



Water flowing in a tube will be retarded by any sudden angle in the tube. If the ajutage of a jet d'eau have not a gentle and uniform sweep where it is turned, the jet of water will not reach the height which it ought to do by calculation of the height of the reservoir of water from which it descends—it will go higher from the tube A than from B. This circumstance explains the uniform and parabolic curve which the great artery of the body takes in first ascending from the heart. It explains also why the branches of the great artery go off at different angles, according to their distance from the heart, or, in other words, why they pass off at smaller angles with the stream the farther the artery recedes from the heart.

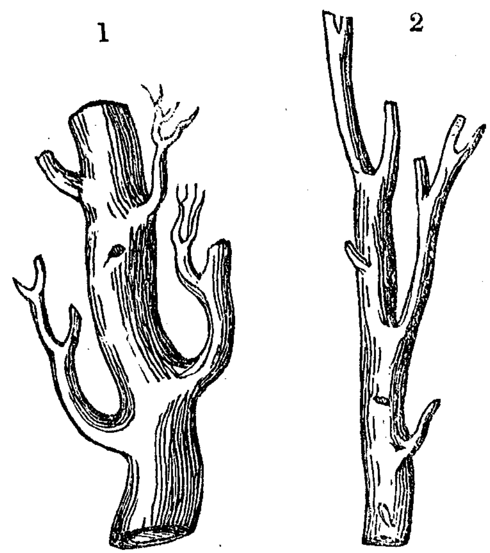
In the distribution of water-pipes, it is very necessary to attend to the angle at which the small pipe is attached to the greater one, not only because a pipe being bent abruptly causes loss of motion from the impulse of the fluid against the side, but also from another well-known law of hydraulics.

If a pipe be fixed into another so as to join it at an angle contrary to the direction of the stream, the discharge into that lateral branch from the larger tube will not only be much smaller than we might estimate by the diameters of the tubes, but, in certain circumstances, it will discharge nothing at all; nay, on the contrary, the water would be drawn from the lesser tube into the greater, until the lesser tube be emptied, and air be sucked in.

Bernouilli found that when a small tube B was inserted into the side of a horizontal conical pipe A, in which the water was flowing towards the wider end C, not only none of the water escaped through the small tube, but the water from a vessel placed at a considerable distance below was drawn up through the tube B into the pipe A. (See fig. at p. 126.)

With these facts before us, we turn with interest to what the anatomist too often contemplates with unconcern, we mean the different curves in the branching of the arteries and veins; for by this law of hydraulics the junction of the branches and trunks of the arteries and veins ought to be different, as the one vessel, the artery, carries the blood out from the heart, that is, from trunk to branch—and the other vessel, the vein, carries it in the opposite direction towards the heart, or from branch to trunk.

And in matter of fact, their branchings are very different, and characteristic of the vessels. We have heard a teacher of anatomy express himself in this manner: "The arteries are active and powerful vessels, which carry the arterial blood out from the heart—and they receive the forcible impetus of the heart. When they are wounded, the man bleeds to death;—therefore, nature conveys these vessels into the recesses of the body, taking advantage of every protecting bone—conveying them so that the bones and the muscles protect them. There are no irregularities in their course, and their branches go off at a determined angle, and never irregularly; but the veins," he would continue, "are vessels of less importance—they convey the blood back to the heart, with a languid motion, and if they are wounded the blood flows with so diminished a force that you can stop it with the pressure of your finger; accordingly, nature is more negligent of them, they run in all their courses irregularly—some deep, some superficially; and their branches join their trunks with awkward irregular curves and elbows."



This is in good feeling, and is in part true; but it contains somewhat of the error which runs through most anatomical discourses, of supposing things are irregular, as if the objects in view were inartificially and imperfectly attained. From inattention to the hydraulic principle, he seemed not to have considered that the connection of trunk and branch must vary according to the direction of the stream,—that the direction of the branch, which is adapted to lead the stream from the trunk into the branch, must be altered when the design is to convey the fluid from the branch into the trunk.

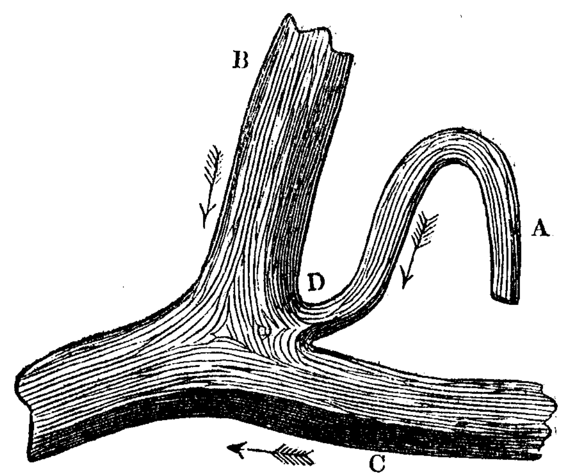
The reader will now understand, that the branch of the artery (No. 1, p. 247) gently diverges from the direction of the stream, while the branch of the vein, in No. 2, enters abruptly and at right angles. We may illustrate this by observing, that if we could suppose the vein substituted for the artery, and the artery for the vein—if the vein carried the blood outwards, instead of towards the heart, and the artery conveyed the blood back to the heart, the blood could not run in the circle; it would be retarded, and congestion would take place, somewhere in its course.

We have seen by the demonstration above, that if the veins of the human body were rigid tubes, and if a hole were made in their sides, air might be drawn in, instead of blood flowing out. This is a matter of vital consequence, for if a very little air be blown into the veins of an animal, it dies in an instant, and there is no suffering nor struggle, nor any stage of transition, so immediately does the stillness of death take possession of every part of the frame.

In conversation with Napoleon's celebrated surgeon, Baron Larrey, on the case of a young man wounded in the neck, he said he had no hesitation in declaring th cause of death to be, air drawn in by the veins of the neck, and he quoted instances occurring at the battle of Wagram. These circumstances greatly increase the interest of an experiment made by Dr. Barry, who found that on introducing a tube into the vein of the neck, and placing the other end of the tube in a vessel of water, the water rose during inspiration. The difficulty of explaining this arises from those veins being membranous tubes,

and consequently compressible; but in the act of inspiration, not only are the ribs and breast-bone raised, but the muscles of the neck attached to the collar-bone rise from the veins of the neck. By this means, instead of suffering the compression of the incumbent parts, the atmospheric pressure is taken off the veins; they are brought to the condition of rigid tubes; and the principles of hydraulics explain the rest. Thus the figure given at p. 128 is a reservoir emptied by a perpendicular tube, into which a smaller tube is inserted. The water descending by the larger tube, will draw the water up through the lesser tube, so as to empty the glass in which its lower end is immersed.

We shall here give an example of the manner in which the trunk of the absorbent system joins the venous system, a circumstance which has not escaped the notice of anatomists. The absorbing or lymphatic system consists of a set of vessels different from arteries and veins, which imbibe by a sort of capillary attraction at their extremities, and convey their fluids towards the centre, without any such impulse as the proper blood-vessels receive from the heart. The stream in the trunk of this vessel has no force to impel it into the stream of blood in the veins; it enters, therefore, in this manner.



A is the trunk of this system, called the thoracic duct;

B is the great jugular vein descending from the head, and C the great vein coming from the arm. These veins join at an angle, and the streams from them, in the direction of the arrows, leave a point between them at D, where there is no pressure. If two tubes enter into a larger tube obliquely, and the water be flowing from the lesser tubes into the greater one, and if a hole be bored at the angle of their union, the water will not escape at that hole. Therefore the fluid from the thoracic duct A meets with no impediment at the point D; when entered, we have seen, by a former diagram, how the attraction of the more forcible stream will draw the contiguous fluid after it. By this contrivance, if we may use the word, the fluid in the absorbing system finds access to the red blood, and is carried into the heart.

We might continue this subject by considering the influence of respiration on the circulation; but we shall pursue the inquiry into the hydraulic principles, as applicable to the circulation, independently of pneumatics.

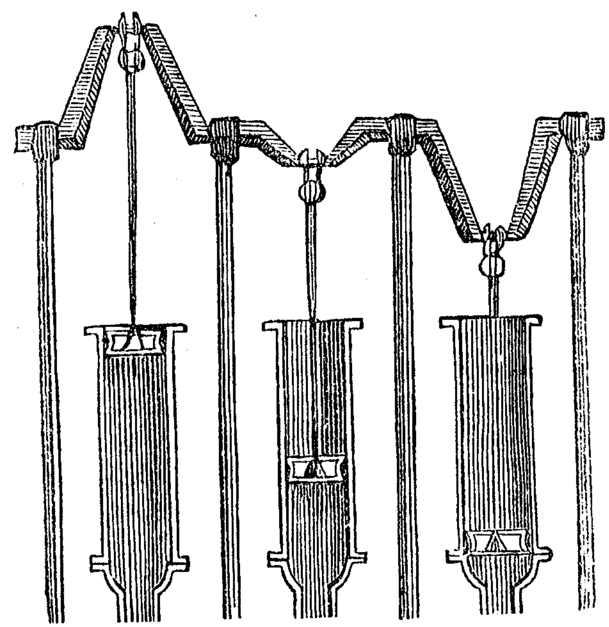
The law of inertia, which is of easy comprehension as it regards solids, is also applicable to fluids; it is easier to keep a column of water in a pipe in motion, than to put it into motion from a state of rest.

In a forcing pump, when after each movement of the piston the column of water becomes stationary, power is unnecessarily lost by bringing the column of water, which is in this state of rest, again into motion; but if a second blow of the engine be given to the column of water whilst it is yet moving, it is found to be more easily pressed forward, and no part of the force is lost in urging it from a state of rest into motion. This is evinced in the contrivances of the engineer. He employs two forcing pumps instead of one, and he so applies his lever as to operate alternately on the one and the other; to the end that the water in the pipe may be kept in uninterrupted motion. Let us apply this principle to the circulation of the blood.

If the heart were the only power forcing on the blood, there would be a cessation of motion after each pulse of the heart, and therefore a great part of its power would

be lost. This explains why there is a power in the artery as well as in the heart. The artery being muscular, seconds the operations of the heart; its muscularity, and the muscularity of the heart, are powers exercised alternately, and which, acting like the double stroke of the engine, permit no interval to the motion of the column of blood. If the heart had to act upon a column of blood at rest, not only much of its force would be unnecessarily exhausted, but it would be excited to propel an inert body, and a dangerous shock would arise from the resistance.

If we pursue this subject, and inquire what is essential to such a hydraulic machine as we are contemplating, we shall perceive that the engineer meets with a difficulty in adjusting the powers of his two pumps, and finds an interval, or pause, in the application of their forces.



To obviate this he makes three cylinders, the pistons of which are moved by a crank, which so orders the descent of the pistons as to fill up this interval, so that one of the pistons shall be always descending; and these pumps propelling the water into a common tube, there is no interval to the motion of the fluid through it.

By this example we are led to look for something corresponding in the machinery of the circulation. We find no third active power, however; yet we find a quality in the blood-vessels which answers the purpose much better. But to comprehend this, we must observe that the engineer has a more admirable contrivance than this of a third pump to adjust the action of the other two.

He confines a body of air which, by its elasticity, performs the office. The pipes of two forcing pumps are carried into the reservoir B; they convey the water up to C, by which time the air is compressed, and its elasticity thereby increased; that elasticity is exerted without interval, and, acting on the water C, propels it into the tube D uninterruptedly. (See figure at p. 132.)

Just such an elastic property is possessed by the arteries. The great artery which goes out from the heart, as we have had repeated occasion to observe, makes a sweeping curve; it is capacious, and is the most perfectly elastic of anything in nature. Here then we have the three powers which the engineer finds necessary to employ. We have the alternate action of the heart and artery, and we have an elasticity which, though passive, is essential, both to the uniform flow of the blood, by filling up the interval in the action of the two powers, and to the safety of the engine itself; for without this elasticity there would be such a jar as must speedily destroy the mechanism.*

There is nothing more admirable than the influence of this elastic power; it is greatest in the coats of the artery near the heart, weaker in the coats of that artery

* But does the blood flow uniformly? Not precisely so in the arteries, since the stroke of the heart is more powerful, or rather more concentrated, than that of the arteries. During the contraction of the ventricle of the heart the artery is dilated. but it is never emptied; and the flow of the blood forwards in the course of the circulation is not for an instant interrupted.

as it recedes from the heart; this very evidently declares its use: but we shall take a more sufficient proof, although an unhappy one.

As life advances, the arterial system loses much of its elasticity, and becomes rigid. This is so common an occurrence that we can no more call it a disease than the stiffened joints of an old man; it is the forerunner or the accompaniment of the decline of life. But this sometimes takes place too early in life, and to an extreme degree; and from its effects we must call it morbid; for it not unfrequently happens that the muscular power of the heart being still entire and vigorous, the arteries can no longer sustain it. They are not now endowed with that power which, yielding to the heart's action, resists, and recoils the more it yields—which takes off all sudden shock, and which in yielding wastes no power, since on its recoil it gives as much force to the acceleration of the blood as was lost of the heart's action. The artery then becoming rigid, yields indeed to the heart's impulse, but has no recoil. It is permanently dilated or enlarged. It is now called aneurismal. A stronger impulse from the heart, excited by inordinate action or passion, chips and bursts the now rigid coats of the artery. If the breach be sudden, it is death; if it be gradual, a pouch forms—a true aneurism. And now we have the proof we require; for this bag coming to press upon the solid bones, they are destroyed. That action of the heart which was so lightly and so easily borne whilst the vessels were elastic, now beating upon a solid structure, in a short time destroys it. Thus we are led to a more accurate knowledge of the fine adjustment of the active and resisting properties in the circulating vessels during youth and health, by what takes place on a very slight derangement of those powers.

CHAPTER II.

THE ILLUSTRATIONS FROM MECHANICS MAY BE CARRIED TOO FAR. PECULIAR PROPERTIES OF LIFE IN THE BODY. THEY DIFFER IN QUALITY. THEY HAVE AN ADJUSTMENT TO EACH OTHER, MORE ADMIRABLE THAN THE MECHANICAL CONNEXION.

We are the more desirous of entering upon this subject, that we may prevent the reader from founding a false conclusion upon the very mode in which we have hitherto proceeded, that of showing design in every part of the animal structure by taking our illustrations from the mechanism of the body.

When we have admired the connections of the several parts, or organs, thus made manifest by comparison with machinery, we may go too far, and say, that the material structure and mechanical relation are to be found in still greater minuteness and perfection in the finer textures of the body, proceed to call this organization, and erroneously conclude, that out of organization comes Life. The very term organization misleads; yet it implies something constructed, in which one part cooperates with another; but nothing more. Taking the body as a whole, there are undoubtedly instances of such co-operation, but it is in vain to seek the explanation of life from this; since life exists in simple and uniform substances, where there is neither construction nor relation.

Now, although there are mechanical construction and relation, as we have seen, in bones, muscles, and tendons, the phenomena of the body result from a dependence established among the living properties, not the

mechanical. The highest medical authorities have seen reason to conclude that life is an endowment, not resulting from organization or construction, but, on the contrary, producing it; in other words, that the living principle attracts the new matter, arranges it, and, in order to its continuance and perfection, alters it, and effects a continual revolution in it. For there is nothing more curious than the uninterrupted and rapid change of the material of the animal body, from the first pulse of life to the last breath that is drawn; of which we shall give abundant proofs before we close this inquiry.

In first approaching the subject we are blinded by familiar occurrences, and cannot comprehend all the links by which the visible phenomena of the living body are produced. Probably most of our readers believe motion to be a necessary consequence of life, and the very proof of its presence. The peasant stirs up an animal with his staff, and if it does not move he is satisfied that it is dead; and such is the experience of mankind. We do not reflect that many different qualities of the living powers must be exercised before sensibility is shown in its visible sign, the motion of the creature. It is not necessary that the parts shall lock into each other like the cogs of wheels;—the connections established are of a different kind altogether. Each part possesses a property of life entirely distinct from the other, and this property of life may exist in the individual part (for a time at least) without that co-operation of the whole which is necessary for the motions of the animal.

This quality of life is, in one respect, like gravitation in matter; that is, when the mass is broken into parts, each division has its proportion of the endowment, and so the separated parts of a living creature possess life. But here the resemblance ceases; gravitation is the same quality in every part, and uniform in its effects, whilst the life is exhibited by qualities differing in every part of the animal body. Did these parts possess qualities exactly similar, they would remain at rest, and though combined, they would not influence each other.

It is the different powers brought into combination that produce the motion of the whole animal.

If a man fall into the water, and is dragged out motionless, and has ceased to breathe, each part of his body may still possess its property of life. Although the combinations have been destroyed, he may be revived by exciting action in some part of his system. Life still remains in brain, and nerves, and heart, and arteries, and in the muscles, which should enable him to breathe; but the mutual influence, the bond of their united operations, is broken. We may take the analogy of a machine, and say that the wheels are stopped; but this is in fact a very different thing; it is the operation of the living influence that is stopped; for we repeat that nature (by which, of course, is always to be understood the Author of Nature) has combined the organs not mechanically, but by properties of life.

Artificial respiration draws after it the action of the heart, because the sensibility of the heart is made respondent to the lungs. Pulsation of the heart, excited by the motion of the lungs, is followed by the action of the arteries; these organs in operation drive the blood through the frame, and by the circulation the susceptibility of each part to impression, which had been weakened, is restored. Action and reaction are re-established; but these actions are not like those of a machine, they are living properties; sensibility in one part, contractility in another; and after a variety of these internal sensibilities have been for some time in operation, the man gives outward token of recovery.

So a person recovering from fainting, after sobbing and irregular breathing, has the respiration renewed; in succession other parts recover their sensibility and resume their places in the circle of relations; the skin is capable of being stimulated, and the limbs are capable of motion; the eyelids are opened; by and by the nerve of the eye is sensible to light, and the nerve of the ear to sound; and, finally, the faculties of the mind are roused, and its control over the body re-established.

The whole separate endowments of life in the different parts resume their offices;—the last in the train; only the property of the muscle to contract is alone observed by the uninformed, and voluntary motion is the token of entire restoration.

We can imagine a half-learned person to act very foolishly in the attempt to restore the apparently drowned. He has been told that we draw in vital air, and breathe out what is unfit to support life; he imagines that it can be of no use to distend the lungs of the drowning person with his own breath, and precious time is lost. Whereas, the mere distension of the chest, that is, of the lungs, followed by the compression of the chest, and again by the distension, and so on alternately, is the *play of the lungs*, which by sympathy draws the heart into action, and in succession all the vital organs. This is not what chemistry teaches; chemistry shows us that the vital air influences the blood; and it is true that the blood, being refreshed or impregnated with the vital air, renews the properties of life. But this effect on the blood could never take place unless there were some previous consent or sympathy, putting the organs into operation. We repeat that the consent of organs is not the effect of mechanical adaptation, or of chemical action, but of relation established among the vital properties.

If a man be struck by lightning, he has not merely the vital operation of respiration stopped, as in the case of the drowning man, in whom every organ continues to possess its property of life; he is not like a man struck on the head, where one vital organ is so disturbed that the circle of vital actions is broken; in this instance the electric fire passes through every fibre and every organ; all the qualities of life, whether residing in the brain, nerve, or muscle, are instantaneously destroyed; and the moment of death is the commencement of dissolution.

Mr. John Hunter illustrated this somewhat familiarly. If you bruise the head of an eel, its body writhes; but if it be taken by the tail, and struck on the flag-stone, so that every part of its body receives the shock, then all the parts are killed, and it remains motionless. When an animal is killed by that violence which injures one important organ, the property of life remains for a certain time in every part; those parts have no correspondence, and there is no outward token of life; but the vital principle is still capable of exhibiting one of its most important properties; it arrests the operation of those chemical affinities which belong to dead matter.

Thus the reader perceives, that, although he be led on to comprehend the design or intention manifested in the structure of the body by mechanical instances or comparisons, it is when we contemplate the influence of the living principle, that we have a higher conviction of the Omnipotence which has formed every creature, and every part of each creature, with that appropriate endowment of life which suits it to act its part in the general system.

We must learn to distinguish between the death of the animal and the death of the parts of the animal—between apparent death and dissolution, or the separation of that quality which distinguishes living matter.

Viewing the subject generally, as Mr. Hunter said, there are not two kinds of matter, but two conditions of matter. It is at one moment forming beautiful combinations, as in the flower, through the principle of life, and, at another, it is cast away as noxious, undergoing changes by decomposition, from chemical processes solely. The want of combination in the whole animal body exhibits apparent death. The loss of life in all the parts of an animal body is absolute death, and the material becomes subjected to the influence of the chemical affinities instead of being urged into motion by life.

The jackstone produces motion in one part of a machine; that, varied by mechanical influence, is communicated to a second; from the teeth of one wheel it is communicated to the corresponding leaves of the pinions, and from the pinions to the fusees. But what a base notion it is to suppose that the mere property of weight in the jackstone is like the influence of life!

The weight is the power, in the language of mechanicians; but it does not reside in the parts of a machine, nor does it exhibit different qualifications in these parts. Separate them, and they are nothing. On the contrary, no one part of an animal body is in this manner dependent on another for its property of life. The property is inherent in the part itself, and the wonderful thing is that each property in the several organs corresponds with the others, so as to form a circle of vital operations. There is no transmission of power, in all this, from part to part—no train of connection to be traced as from the jackstone, or the spring, along the parts of the machine. There is, therefore, in truth, no resemblance between machinery and the influences in operation in a living body. What is to be admired in a living body is not merely the adaptation of bones, muscles, and tendons, forming a mechanical apparatus, but rather the different qualities which life bestows upon different parts; these qualities put the parts into relation each according to its place in the circle of the economy; and among innumerable properties of life in the individual parts, produce that perfect co-operation as if one principle only actuated the whole.

When a person moves under the direction of the will, nothing can be more simple to our understanding, because we do not attempt to trace the links, far less to estimate the powers in the several parts influenced during this familiar action. But if there be the slightest diminution of sensibility of one nerve so that it shall not transmit sensation; or if there be any disturbance which retards in the least degree the transmission of the will along another appropriate nerve; if the muscle be benumbed, or have lost its irritability; if the action of the blood-vessels has been either diminished or increased beyond their ordinary course, either in the organs of sense, the brain, or nerves; we are appalled by the consequences. The impressions of things are not felt; the senses are unexercised; the limbs remain inactive; one half, or the whole, of the body is a load, as if there were a living being in a dead body—a body whose parts refuse their office, appearing dead, though they are not so. The correspondence of their living qualities has alone been disturbed; the movement which results from the whole is stopped, and there is apparent death.

What confusion then must be engendered in the minds of those who would confound the phenomena of life, as presented in the entire framework of the body, with those separate qualities of life which, residing in the several parts, must enter into combination for the motion of the whole! The next step of this unphilosophical manner of treating the subject, is to make the organization the source of the living property,—as if any combination of organs could produce life,—as if those organs could have motion without the distinct endowments of life in their separate parts,—as if they co-operated mechanically, and not from the correspondence among their living properties. Those who thus reason mean to say that parts are made so finely as to move of themselves, one part propelling another, and the motion of the whole producing life. It is quite clear that this confusion of ideas arises from contemplating the phenomena of the perfect animal, in which all intermediate influences are confounded. On the other hand we present this proposition.

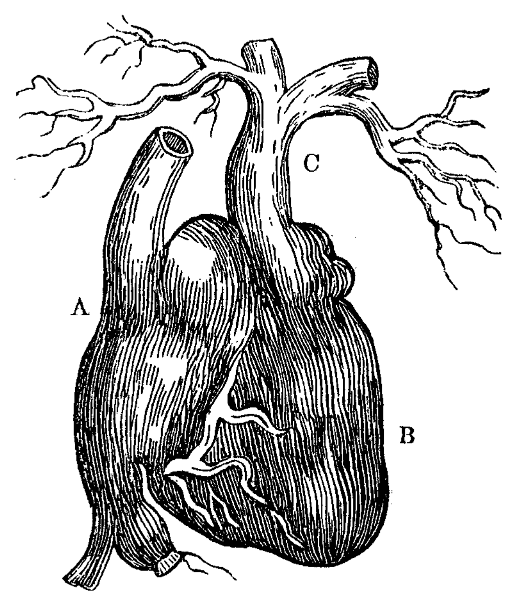
The several *simple* substances of a living body have each an endowment of life bestowed upon them. Let us take the obvious qualities, of sensibility—the power of transmission — and the power of motion; each of which is appropriate to a particular substance. When these qualities are put in relation, impressions may produce motion, and thus there are three distinct properties of life brought into operation. Where is the organization or construction here? Without those living endowments these parts would be inoperative, in whatever juxtaposition placed. The mechanical construction of the body is one thing: and we are able to admire it, because it can be illustrated by comparison with our own contrivances; the combination of living properties is another and an entirely different thing.

We here reach the limit of philosophical inquiry. Hitherto all has been flattering to the pride of the creature; but we must now humbly acknowledge the inscrut-

able ways of the Creator; and ceasing to trace the origin of life, more than we do that of gravitation, we should be occupied in observing its laws, not in exploring its source.

We shall take an instance to illustrate the difference betwixt the mechanical connection of parts and their relations through the living properties; and it will, at the same time, show how curiously the living properties and the mechanical properties are made to correspond with each other.

A stream of water is converted into a mechanical power; it fills a cistern, which is attached to a lever; the cistern descends by the weight of water; by its descent a valve is pushed open; the water escapes, and the cistern ascends, and remains so, till the stream flowing into it again, depresses it. Thus the regularity of the supply of water gives regularity of motion to the machine. Compare this with the heart.



We may describe the heart as consisting of two cavities, the one called the *Auricle*, and the other the *Ventricle*. The sinus A receives the blood returning by the veins, and gradually filling, like a cistern, it becomes so distended, that its muscular power is excited; it contracts, and delivers the blood with a sudden impetus into the second cavity, or the ventricle B; which, in its turn, excited by the distension, contracts, and propels the blood into the artery C. Here the action of the heart is accounted for, by its mechanical distension with the blood: and the regularity of its motions necessarily corresponds with the regularity of the supply. The distension produces action, and the propulsion of the blood from the cavity allows a momentary state of rest, until another volume of the blood excites another pulse.

But we have now to observe, that when this irritability or muscular power was bestowed upon the heart, it was directed by a law entirely different from the irritability, as possessed by other muscles. A property of alternate activity and rest was given to it, quite unlike the contractility of other parts; and accordingly when the heart is empty, when there is no distension of blood at all, the two cavities will continue their alternate action. Nay, if the heart be taken from the animal recently dead, it will continue to act in regular successive pulses, first the one cavity, and then the other, and so on successively for a long time, until the life be quite exhausted. The two cavities will thus continue in alternate action, as if they were employed in the office of propelling the blood, when there is no blood contained within them. It is superfluous to observe, that no such thing could happen in the case of the cistern and lever, were the stream of water to cease running.

Thus we distinguish two things quite different—a mechanical or hydraulic provision, by which these little cisterns, the auricle and ventricle, shall be regularly supplied, and alternately filled and emptied—and the property of contraction in the heart; not a mere property of contraction from irritation, as in the other muscles, but a property far more admirable, since the irritability or power of contraction of the part is ordered with a reference to its office—that it shall contract and relax in regular and rapid succession, and continue its office unweariedly through a long life. The living property of the heart exhibits a variety adapted to its office, and a correspondence still more admirable than the mechanical relation.

We are thus particular in distinguishing the mechanical adaptation of parts from the co-operation of the vital influences residing in the several parts; for there are many who will take the illustration from mechanics, and stop their inquiry there, and who entertain a confused notion of the dependence of the life of the body on its mechanism.

Another mistake, which some philosophical inquirers entertain, is to fancy that the principle of life is of a galvanic nature. There is indeed an unwillingness in men to acknowledge that their powers of reason are exhausted, and that they have arrived at an ultimate stage; they would fain set up some contrivance to hide the humiliating truth. Whatever notions have prevailed in the schools at different epochs, of heat, electricity, or galvanism, we find an attempt to explain the phenomena of life by an application of the powers, with which they have been successful in their physical inquiries. Experiments without reason are equally delusive with hypotheses; those who will not give themselves the labour of thought, desire to witness striking phenomena; wonder-struck, they believe that they are engaged in experimental investigation, when their state of mind is little better than idle amazement. A calf's head is made to yawn, or a man cut down from the gallows to move like a figure of cards pulled with strings; the jaws move, and the eyes roll, and this is done by conveying the galvanic shock to the nerves; here it is supposed that nothing less than the principle of life itself can work such wonders, and that galvanism is this principle.

Putting aside the circumstance already stated, of life exhibiting totally different phenomena in union with different parts, is there any point of resemblance between galvanism and life? Does tying the nerve stop the influence of galvanism, as it does the influence of life? Does galvanism course along a cord when it is surrounded by matter in contact with it of the same nature? Can life pass out of one body into another, like heat, or electricity, or galvanism? Can *they* be contained by a thin membrane? Does life pass equally through all the parts of a moist animal body as one uniform influence, like galvanism?

In no circumstance is there a resemblance, and the whole phenomena resulting from galvanism transmitted through an animal apparently dead, are fairly to be attributed to its being a high stimulus conveyed through the moist animal body, and exciting the powers which remain insulated in the several parts; and in exciting those forces, far from renewing them, it exhausts them altogether.

The uses made of galvanism in the explanation of the living phenomena, should make sensible men very cautious how they carry the legitimate inductions of chemical science into another department. They will not submit to call the irritability or contractility of a muscle an endowment of life, but seek to explain it by organization. They employ the microscope; they find the ultimate fibre to be some thousandth part of an inch in breadth; they see plicæ or folds; they imagine them to be cells into which the fibres are divided; they furnish these cells with two different gases, and explode them by some galvanic influence of the nerves; and the explosion by dilating the cells in one direction, causes the contraction in another. This is the theory of muscular action at the period of the discovery of the gases; and some such idle hypothesis, supposed applicable to the laws of life, accompanies every considerable improvement in chemistry.

In the most modern and the most popular French work on Physiology, by Mons. Richerand, he says, "What appears to me by much the most ingenious opinion, and which carries with it the greatest probability, is that which supposes the contraction of the muscle to depend on the combination of hydrogen, carbon and azote, and other combustible substances which exist in the fleshy fibre, with the oxygen conveyed to them through the arteries." But he adds, as if he had perfected the

theory, "it is also necessary to suppose, that a nervous fluid is directed through the muscle to determine the decomposition, as the electric spark forms water out of two gases."

Such is the chemical theory of muscular motion; it betrays an entire misunderstanding of the phenomena of muscular motion, and of the beautiful provision in every muscle for its appropriate office. The muscles, which are subservient to the organs of sense, differ in their operations altogether from the voluntary muscles of the limbs. The hollow muscles, as they are termed, those which carry down the food, and which carry round the blood in circulation, vary in their time and manner of acting according to their offices; but what conception can he have of such adjustment of powers, who is entertaining himself with a theory, that supposes a sudden explosion to take place in the fibres of the muscle at their time of action? Inductive reasoning, which has carried men to the highest acquirements in physical science, is here laid aside; conjectures totally inconsistent with the phenomena of life are employed in its stead; and the useful philosopher becomes a very indifferent physiologist.

CHAPTER III.

OF SENSIBILITY.

UNDER this head are comprehended, not any sentiment or feeling of the mind, but the sensations of the body.

We form our notions of sensibility from that of the skin; and it is no doubt necessary that we should do so. It is in constant communication with things around us, and affected by their qualities; it affords us information, which corrects the notions received from the other organs of sense, and it excites our attention to preserve our bodies from injury. We are so familiar with the painful effects of injuries upon the surface, that there is nobody who does not imagine that the deeper the injury, the more dreadful the pain. But, on the contrary, it is a well-established fact, that to such irritants as would give the skin pain, the internal parts are totally insensible. And it is equally certain, that though the nerves, the instruments of sensation, are incapable of producing any perception without the brain, yet the brain itself, the part which is the seat of intellect, and to which every impression must be referred before we become conscious of it, is itself as insensible as leather. These considerations show us that sensibility to pain is not a necessary result of life, and they naturally lead to the inquiry for what purpose is sensibility bestowed, and how is it distributed in the body?

We have first to show that the skin has sensibilities exactly suited to the functions it has to perform. Science no doubt informs us, that warmth and cold are only relative degrees of heat; to the skin they are distinct sensations, and excite in different ways both the mind and the bodily functions. Cold braces and animates to exertion, whilst the warmth which is pleasant to us, is genial to all

the operations of the animal economy. Their alternations are the most constant sources of our enjoyment, and at the same time conduce to exertion and to health. All this, however, belongs to the skin exclusively; parts internal, although peculiarly sensible to their proper stimulus, give no indication of sensibility to heat; if there be internal sensations of heat, they are morbid and deceptious. Molten lead would produce pain and death being poured into the interior of the body, but the sensation of burning is a property of the surface only. It is the excess of that particular sensation, which is calculated, like the other endowments of the skin, to suit the medium in which we live, and to force us to the regulation of the temperature necessary to preserve life.

Touch, or the sensibility to bodies pressed upon the skin, is likewise a distinct and appropriate sense. The sensibility of the skin to pricking, cutting, or tearing, is also in curious contrast with the sensibility of the solid internal textures, as bone, cartilage, and ligament. We have arrived at the full comprehension of this subject very slowly. Disagreeable experiments have been made, but the following is as interesting as it was innocently performed. A man who had his finger torn off, so as to hang by the tendon only, came to a pupil of Dr. Hunter. "I shall now see," said the surgeon, "whether this man has any sensibility in his tendon." He laid a cord along the finger, and, blindfolding the patient, cut across the tendon. "Tell me," he asked, "what I have cut across?" "Why, you have cut across the cord, to be sure," was the answer. By such experiments it became very manifest, that bone, gristle, and ligament, were insensible to pricking, cutting, and burning. Were they, therefore, insensible? The reader will answer—Surely, it is a matter proved. But before we finally decide, let us take this into consideration,—that the sensibilities of the body differ in kind as well as in degree; and every part has its peculiar kind, as well as its degree; and every part has its kind of sensibility with reference to its function, and also with reference to its protection from violence. If the membranes between the bones of our great joints, or the cords which knit the bones, were sensible in the same manner and degree with the skin, we should be incapable of motion, and screwed to our seats; as the man appears to be who has a violent attack of acute rheumatism.

But although these bones and cartilages, or gristles, and ligaments, be not sensible as the skin, or the surface of the eye, they possess that which is suited to their condition, which permits their free use, and yet limits that too free exercise which would be injurious to their textures, or raise inflammation in them. The ligaments and tendons, then, which are insensible to pricking, cutting, and burning, are sensible, nevertheless, to stretching and tearing! It is remarkable that such men as Dr. Hunter and Haller, the luminaries of their science, should have held the opinion that the bone and the membrane which covers it (the *periosteum*), the gristles or cartilages, the ligaments of joints, and the tendons of muscles were insensible parts, and yet be in daily attendance on those who suffer the pain of a sprained ankle, where there are no parts to suffer but those enumerated, and where the pain, excessive in degree, was felt in the instant of the sprain. These considerations explain to us that pain is the safeguard of the body. This capacity of conveying painful impressions to the mind is not given superfluously to all parts; on the contrary the safe exercise and the enjoyment of every part is permitted without alloy, and only the excess restrained.

This subject is finely illustrated by the apparent insensibility of the heart. The observation of the admirable Harvey, the discoverer of the circulation of the blood, is to this effect. A noble youth of the family of Montgomery, from a fall and consequent abscess on the side of the chest, had the interior marvellously exposed, so that after his cure, on his return from his travels, the heart and lungs were still visible and could be handled; which when it was communicated to Charles I., he expressed a desire that Harvey should be permitted to see the youth and examine his heart. "When," says Harvey, "I had paid my respects to this young nobleman,

and conveyed to him the king's request, he made no concealment, but exposed the left side of his breast, when I saw a cavity into which I could introduce my fingers and thumb; astonished with the novelty, again and again I explored the wound, and first marvelling at the extraordinary nature of the cure, I set about the examination of the heart. Taking it in one hand and placing the finger of the other on the pulse at the wrist, I satisfied myself that it was indeed the heart which I grasped. I then brought him to the king, that he might behold and touch so extraordinary a thing, and that he might perceive, as I did, that unless when we touched the outer skin, or when he saw our fingers in the cavity, this young nobleman knew not that we touched the heart!" Other observations confirm this great authority, and the heart is declared insensible. And yet the opinions of mankind must not be lightly condemned. Not only does every emotion of the mind affect the heart, but every change in the condition of the body is attended with a corresponding change in the heart: motion during health—the influence of disease—every passing thought—will influence it. Here is the distinction manifested. The sensibility of the skin is for a purpose, and so is the sensibility of the heart. Whilst the skin informs us of the qualities of the external world and guards us against injury from without, the heart, insensible to touch, is yet alive to every variation in the constitutional powers, and subject to change from every internal influence.

There is in the several organs of the body, as it were, a distinct life; that is, they possess sensibility, the grand endowment of life, necessary to their condition and adapted to their appropriate stimulus. The impressions made upon them will sometimes rouse them into activity, or call muscles into action which are necessary to their functions or for their protection; and this oftentimes without reference to the mind at all, and consequently without our consciousness.

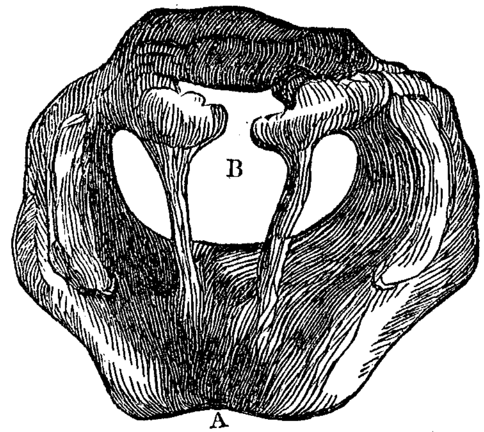
Perhaps we have the most agreeable example of this in the eye. That organ has been selected, in the Preliminary Discourse of the Objects and Pleasures of

Science, as showing how mechanical advantage is taken in the arrangement of the muscles to produce velocity of movement in guarding the eye. But this fine mechanism would be lost if the excitement depended on our will,—if there were not a sensibility appropriate to the action, and an influence quicker than thought. It is not by feeling the pain of the offensive body, or by estimating its dangers and acting on the conviction, that we close the eye to avoid injuries. This would be an operation all too slow for the intended purpose; and therefore the muscles, possessing these extraordinary provisions, are put in relation with a sensibility more admirable still. So when a light foreign body touches the eyelashes, they give alarm, and cause a motion both of the eyelids and eyeball quicker than thought. The eyelashes, seated on the tender extremities of sensitive nerves, preserve the eye in two ways—by guarding its interior from the lateral light, and by exciting the motion of the eyelids, even before the offensive body can touch the eye's surface.

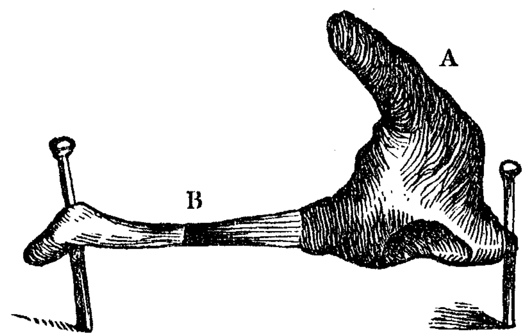
We may take another illustration to show how sensibility, one of the endowments of the living part, is adapted to the mechanical organization, and with an appropriation more admirable than the mechanism. When we speak of the sensibility of the skin, it is still possible to misconceive its nature, and to suppose it accident merely; but in the instance to be adduced, the sensibility is different, and it is put in connection with a hundred muscles; without this high and peculiar sensibility, and its multiplied relations to muscles, independent of volition, the mechanism we are about to describe would be quite useless.

The top of the windpipe is called the *larynx*, and consists of five elastic cartilages. These do not merely keep the sides of the windpipe apart, and the passage for the breath free, but they perform offices important to the economy both of body and mind; they are an essential part of the instrument of voice; they, at the same time, guard the lungs from injury.

The *thyroid* cartilage is the largest of the cartilages of the larynx; it is that we feel projecting on the fore part of the throat called the *pomum adami*, (A.) It is a pro-



tection to the fine apparatus behind it, and indeed this is the reason of its name, (*scutiform*, like a shield.) Within the thyroid stand the *arytænoid* cartilages, (B.) This cartilage is of an irregular triangular form. It is socketed or articulated on the cartilage below, and is perfectly movable. To the corner which projects forwards the



ligament (B) is fixed, and to its other sides five little muscles are attached; these muscles, by moving the cartilage, draw and vary the position of the ligament. It is these cartilages and this ligament, which, vibrating in the stream of air, give the tremor, and vocalize the breath; the tones so produced are articulated in speech.

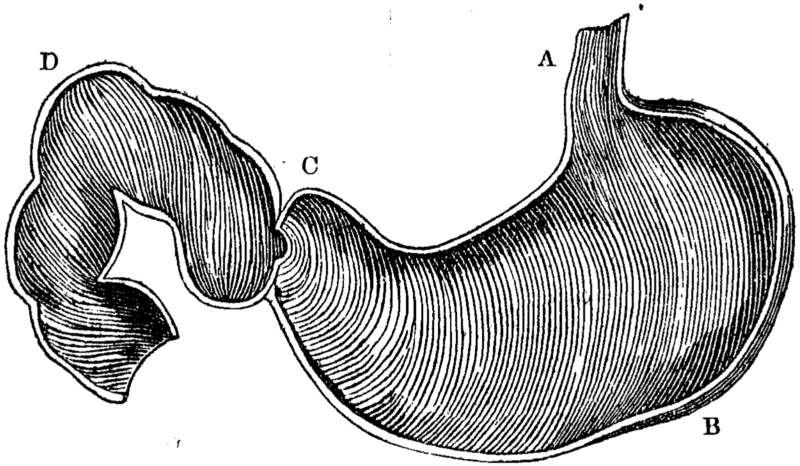
This is a subject far from being exhausted in our philosophical works, and may call for observation afterwards; but at present we may look on these ligaments, not as the *cordæ vocales*, but in another of their offices—forming the slit which opens and shuts in breathing, for the protection of the lungs. But here it is pertinent to remark, that in the structure of an animal body one organ is made subservient to several functions, without interference in the performance of any of them. This is especially true of the larynx. It is one of those uses only, and the least important, that we have at present to observe.

The ligaments being invested with the lining coat, or membrane of the wind-pipe, draw it into the form of a slit like the till of a shop counter, and this is the chink of the glottis, (*rima glottidis.*) This slit opens and closes with every inspiration, moving as we see the nostrils do in breathing. But the most admirable thing of all is the acute sensibility given to this part, and to no other, so that the lightest husk, or seed, or smallest fly, drawn in with the breath, and touching the margin of the chink, is caught there by the rapid action of the muscles and consequent closing of the aperture. Now were the provision for the protection of the lungs to be only thus far perfect, there would be an effectual means of preventing the intrusion of foreign matter into the delicate cells of the lungs, but not for its expulsion from the entrance which it had reached. Accordingly, although the sensibility of the glottis is put in operation with the shutting of the chink, it also animates another class of muscles; viz. all those which, seated on the chest, compress it, and force out the air in coughing; and these combining in one powerful and simultaneous effort, whilst the glottis is closed, overcome that constriction, and propel the breath through the contracted pipe with an explosive force, which brushes off the offending body. There is one thing more, necessary to this most important though familiar action;—the lungs are never empty of air: in breathing we do not fully expel the air; if we did, there would be a period of danger occurring seventeen times in a minute; for in the first part of each inspiration something might be drawn into the wind-pipe which would suffocate. But by this provision of air retained in the lungs more than necessary to respiration, and which it is possible to expel by a more forcible expiration, there is always a possibility of coughing and expelling the offensive thing at any point of time in the act of inspiration.

The sensibility seated in a spot of the throat so beneficently, does not extend into the wind-pipe; for we cannot more admire the perfect adaptation of this living property, than the circumstance of its never being bestowed in a superfluous degree, nor extended where it is not absolutely required. Just as the sensibility of the skin protects the parts beneath, so in the same manner does the sensibility of the top of the wind-pipe protect all the interior of the tube, and the lungs themselves, without the necessity of this property of irritability extending through the whole continuous surface.

The simple act of sneezing affords a very curious instance of the mutual adaptation of muscular activity and the governing sensibility. The sensation which gives rise to this convulsive act is seated in the membrane of the interior of the nostrils, and we are not surprised with the difference of sensation from that in the throat which excites coughing. But is it not a very curious thing to find some twenty muscles thrown out of the action excited by irritation of the nose; and as many excited which were not in the class of those influenced in coughing; and for the very obvious purpose of shutting the passage by the mouth, or at least forcibly driving the air through the nostrils? No act of the will could so successfully propel the air through the nose in such a way as to remove the offensive and irritating particles from the membrane of the nose, and clear those passages.

These last examples of an appropriate sensibility might introduce us to an acquaintance with those internal sensibilities which govern the actions of parts quite removed from the influence of the will; but the description of them may be deemed unnecessary. We shall just hint at the guard which nature has placed on the lower orifice of the stomach, to check the passage which the appetites



of hunger and thirst may have given at the upper orifice (A) to aliments not easy of digestion. This lower orifice (C) is encircled with a muscular ring; the ring is in the keeping of a watchful guard. If we are employing the language of metaphor, it is of ancient use. The Greeks called this orifice *pylorus*, which signifies a porter,* and his office is this.—When the stomach has received the food, it lies towards the left extremity, or is slightly agitated there. When the digestive process is accomplished, the stomach urges the food towards the lower orifice. If the matter be bland and natural it passes, and no sensation is experienced. But if crude and undigested matter be presented, opposition is offered to its passage, and a contention is begun which happily terminates in the food being thrown again to the left extremity of the stomach, to be submitted to a more perfect operation of the digestive powers seated there. It is during this unnatural retrograde movement of the food, that men are made sensible of having a stomach. Yet the sensations, how unpleasant soever, are not to be regarded as a punishment, but rather as a call on reason to aid the instinctive powers, and to guard against disease, by preventing impure matter from being admitted into the

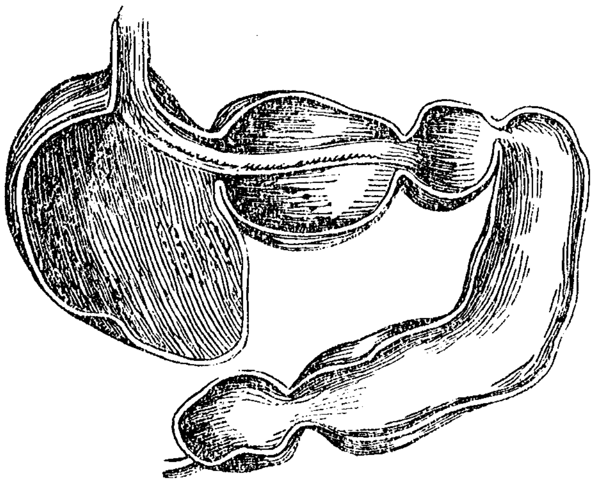
* The upper orifice was called by them *œsophagus*, as it were the *purveyor*, from two words signifying to bring food.

portion of the intestinal canal, which absorbs, and would thus carry those impurities into the blood to engender disease.

Such are a few examples of the variety in the sensibilities of the animal frame; guarding us against external influences when they would threaten destruction to the framework, and adjusting the operations of internal parts too complicated and too remotely situated for the superintendence of reason.

Medical authors, without being empirics, do, notwithstanding, take great advantage of our ignorance. We can all of us take warning from the sensations experienced in the process of digestion, and there can be no harm in giving every man a confidence in the sensibility of his stomach, and in its indications of healthy or disturbed functions. We have the best proof of what we wish to inculcate in the action of the ruminating stomach. A cow swallows the gross herbage, and fills its large first stomach. When it chews the cud, the stomach, by its action, rolls up the grass into distinct pellets, or balls, with as much regard to the office of its being rejected into the mouth as we do in masticating for swallowing. When the ball is brought into the mouth and chewed, it is again swallowed; but in descending into the lower part of the gullet a muscle draws close the aperture by which it passed into the large stomach in the first instance, and it is now ushered into a second stomach, and so successively onwards to that stomach in which the digestion is performed. The curious muscular apparatus by which this is accomplished needs not be described; but surely the sensibility which directs it, which, kept apart altogether from the will, is yet, in its results, so like the operations of reason, presents a subject of just admiration.

The elastic structure of the camel's foot; the provision around its eyes for ridding them of offensive particles; the power of closing its nostrils against the clouds of sand; and its endurance of fatigue—would not enable it to pass the desert, unless there were provisions for the lodgment of water in its stomach, and unless this apparatus were animated by peculiar sensibilities; for there



are muscles to retain the fluid in the cells of its stomach, only permitting it to ooze out according to the necessities of the animal; and there is a muscle, represented in the figure above, which pulls up the one or the other of the orifices of the different stomachs to receive the food from the lower end of the gullet, according to its condition, whether to be deposited merely as in a store, or to be submitted to the operation of digestion.

The surprising thing in all this, is not so much the mechanical provision as the governing sensibility. What, for example, should in the first place impel the grosser food, when collected, into the first stomach? What should, in the next place, and after rumination and mastication in the mouth, carry it into the third stomach; since water is carried into neither of these, but into the cells of the second stomach?

Yet, after all, this only brings us back to a sense of the operations of our own bodies. The act of swallowing, the propulsion of the food into the gullet, and the temporary closing of the windpipe at such a time, is just as surprising. This latter operation is never deranged but by the interference of the will. If the individual attempts to speak, that is, to govern these parts by the will, when they should be left to these instinctive operations; or if terror, or some such mental excitement,

prevail at the moment of swallowing, then the morsel may stick in the throat.

All this shows how perfect the operations of nature are, and how well it is provided that the vital motions should be withdrawn from the control of reason, and even of volition, and subjected to a more uniform and certain law.

But the point to which we would carry the reader is this, that though there are the proper sensibilities of the body, with reference to perception or consciousness, yet there are others no less curious, which control the internal operations of the economy; and that the mechanical provisions are but a type of what is promised to him who will look into the sensibilities of the body for the proof of power and contrivance.

Now the human stomach, though not so complicated in its apparatus of macerating and digesting vats, is possessed of a no less wonderful degree of governing sensibility, which may be trusted as surely as the most skilful physiologist.

We are told that we must not drink at meals, lest the fluid interfere with the operation of digestion; of this there need be no apprehension. The stomach separates, and lets off with the most curious skill, all superfluous fluid through its orifice, while it retains the matter fit for digestion. It retains it in its left extremity, permitting the fluid to pass into the intestines, there to supply the other wants of the system no less important than the digestion. The veterinary professor Coleman ascertained that a pail of water passed through the stomach and intestines of a horse, at the rate of ten feet in the minute, until it reached the cæcum. Drinking at a stated period after meals, say an hour, is at variance with both appetite and reason. The digestion is then effectually interfered with; for what was solid has become a fluid, (the *chyme.*) This fluid is already in part assimilated; it has undergone the first of those changes which fit it ultimately to be the living blood; and the drink mixing with this chyme in the inferior extremity of the stomach, or first intestine, must produce disturbance, and interrupt the work of assimilation.

Looking in this manner upon the very extraordinary properties of the stomach, we perceive how natural it was for physicians to give a name to the sensibility of which we have been speaking. The *Archeus* of Van Helmont, the *Anima* of Stahl, were the terms used to designate this nature, principle, or faculty, subordinate to, and distinct from perception;—a notion entertained, and more or less distinctly hinted at, by philosophers from Pythagoras to John Hunter.

A modern philosopher,* of whom, in this instance, it would be difficult to say whether he be serious or playful, with some plausibility, however, asserts that it might be possible to carry on the business of life without pain. If animals can be free from it an hour, they might enjoy a perpetual exemption from it. Animals might be constantly in a state of enjoyment; instead of pain, they might feel a diminution of pleasure, and might thus be prompted to seek that which is necessary to their existence.

In the lower creatures, governed by instinct, there may be, for aught we know, some such condition of existence. But the complexity and delicacy of the human frame is necessary for sustaining those powers or attributes which are in correspondence with superior intelligence; since they are not in relation to the mind alone, but intermediate between it and the external material world. Grant that vision is necessary to the developement of thought, the organ of it must be formed with relation to light. Speech, so necessary to the development of the reasoning faculties, implies a complex and exceedingly delicate organ, to play on the atmosphere around us. It is not to the mind that the various organizations are wanted, but to its condition in relation to a material world.

The necessity of this delicate structure being admitted,

* Hume.

it must be preserved by the modifications of sensibility, which shall either instinctively protect the parts, or rouse us into powerful and instantaneous activity. Could the eye guard itself, unless it possessed sensibility greater than the skin? Could it guard itself, unless this sensibility were in consent with an apparatus which acted as quick as thought? Could we, by the mere influence of pleasure, or by any cessation or variation of pleasurable feelings, be made alive to those injuries which might reach the lungs by substances being carried in with the air we breathe? Is there anything but the sense which gives rise to the apprehension of suffocation, that would produce the instant and sudden effort which could guard the throat from the intrusion of what was offensive or injurious? Pleasure is at the best a poor motive to exertion, and rather induces to languor and indulgence, and at length indifference. To say that animals might be continually in a state of enjoyment, and that when urged by the necessities of nature, such as thirst, hunger, and weariness, they might only feel a diminution of pleasure, is not only to alter man's nature, but external nature also; for, whilst there are earth, rocks, woods, and water for our theatre of existence, the textures of our bodies must be exposed to injuries, from which they can only be protected by a sensibility adapted to each part, and capable of rousing us to the most animated exertions. Take away pain, and take also away the material world, by which we are continually threatened with injury; and what, after all, is this, but imagining a future state of existence, instead of that in which mind and matter are combined? If all were smooth in our path, if there were neither rugged places nor accidental opposition, whence should we derive those affections of our minds which we call enterprise, fortitude, and patience?

Independent of pain, which protects us more powerfully than a shield, there is inherent in us, and for a similar purpose, an innate horror of death. "And what thinkest thou (said Socrates to Aristodemus) of this continual love of life, this dread of dissolution, which takes possession of us from the moment that we are conscious of existence?" "I think of it, (answered he,) as the means employed by the same great and wise artist, deliberately determined to preserve what he has made."

The reader will no doubt here observe the distinction. We have experience of pain from injuries, and learn to avoid them; but we can have no experience of death, and therefore the Author of our being has implanted in us an innate horror at dissolution; and we may see this principle extended through the whole of animated nature. Where it is possible to be taught by experience, we are left to profit by it; but where we can have none, feelings are engendered without it. And this is all that was necessary to show how the life is guarded; sometimes by mechanical strength, as in the skull; sometimes by acute sensation, as in the skin and in the eye; sometimes by innate affections of the mind, as in the horror of death, which will prevail as the voice of nature, when we can no longer profit by experience.

But the highest proof of benevolence is this, that we have the chiefest source of happiness in ourselves. Every creature has pleasure in the mere exercise of his body, as well as in the languor and repose that follow exertion; but these conditions are so balanced that we are impelled to change, and every change is an additional source of enjoyment. What is apparent in the body, is true of the mind also. The great source of happiness is to be found in the exercise of talents, and perhaps the greatest of all is when the ingenuity of the mind is exercised in the dexterous employment of the hands. Idle men do not know what is meant here; but Nature has implanted in us this stimulus to exertion, that she has given to the ingenious artist—the man who invents, and with his hands creates, a source of delight, perhaps greater, certainly more uninterrupted, than belongs to the possession of higher intellectual powers, and far beyond any that falls to the lot of the minion of fortune.

We believe that every thinking person may have wherewithal in his own sphere to tutor him, and bring him to the temper of mind and belief which we would

inculcate. Yet there is something peculiarly appropriate in the study of our own bodies. In chemistry we are so much the agents as to forget the law, and the law itself seems at least to intermit. But in the changes wrought in the animal frame, the directing power is uniform in its influence, and holds all in harmony of action.

We now learn without difficulty and without mystery, what is meant by organic and animal sensibility. The first is that condition of the living organ which makes it sensible of an impression, on which it reacts and performs its functions. It appears from what has preceded, that this sensibility may cause the blowing of a flower, or the motion of a heart. The animal sensibility is indeed an improper term, because it would seem to imply that its opposite, organic sensibility, was not also animal; but it means that impression which is referred to the sensorium; where (when action is excited) perception and the effort of the will are intermediate agents between the sensation and the action or motion.

We may sum up the inquiry into sensibility and motion thus:—

1. The peculiar distinction of a living animal is, that its minute particles are undergoing a continual change or revolution under the influence of life. Philosophers have applied no term to these motions.

2. An organ possessed of an appropriate muscular texture, and of sensibility in accordance with the moving instrument, as the heart, or the stomach, has the power of action without reference to the mind. The term *automatic*, sometimes given to those motions, conveys a wrong idea of the source of motion, as if, instead of being a living power, it were consequent upon some elastic or mechanical property.

3. There are sensibilities bestowed on certain organs, and holding a control over a number of muscles, which combine them in action in a manner greatly resembling the influence of the mind upon the body, yet independent of the mind; as the sensibility which combines the muscles in breathing.

4. In the last instance a large class of muscles were

combined without volition. But the whole animal fabric may be so employed; as in the instinctive operations of animals, where there is an impulse to certain actions not accompanied by intelligence.

5. A motive must exist before there are voluntary actions, and hence philosophers have supposed that there can be nothing but instinctive actions in a new-born child. But we must distinguish here what are perfect at first, and what are imperfect and irregular, and become perfect by use and the direction of the will. The act of swallowing is perfect from the beginning. The motions of the legs and arms, and the sounds of the voice, are irregular and weak, and imperfectly directed. It is the latter which improve with the mind. From not knowing the internal structure, and the arrangement of the nerves, philosophers, as Hartley, supposed that an instinctive motion, such as swallowing, may become a voluntary act. Volition in the act of swallowing consists merely in putting the morsel within the instinctive grasp of the fauces, when a series of involuntary actions commence, over which we have no more control in mature age than in the earliest infancy. Swallowing is not a voluntary action, and the thrusting the morsel back with the tongue is like putting the cup to the lip. It is the preparation for the act of swallowing that is voluntary, but over the act itself we have no control.

It is an error to suppose that all muscular actions are, in the first instance, involuntary, and that over some of them we acquire a voluntary power. The power of volition over the muscles of the body is provided for by appropriate nerves, and no apparatus which is not supplied with that particular class of nerves can ever, by any exercise or study, become subject to volition. A child's face has a great deal of motion in it, very diverting from its resemblance to expression, before there can be any real motive to the action. It will crow, and make strange sounds, before there is an attempt at speech. But this gradual development of intelligence and acquisition of power ought not to be called the will attaining influence over involuntary muscles; since, in fact, the

apparatus of nerves and muscles is prepared and waits for the direction of the mind with so perfect a readiness, as to fall into action and just combination before that condition or affection of the mind which should precede the action takes place. A child smiles before anything incongruous can enter the mind, before even pleasure can be supposed a condition of the mind. Indeed, the smile on an infant's face is first perceived in sleep.

6. All the motions enumerated above are spontaneous motions belonging to the internal economy; but the external relations of the animal, the necessity of escaping from injury, or warding off violence, require a sensibility suited to those outward impressions, and an activity consequent on volition. Nothing less than perceptions of the mind, and voluntary acts, suited to a thousand circumstances of relation, could preserve the higher classes of animals, and man above all others, from destruction.

All these provisions proceed from an arrangement of nerves and muscles. The mechanical adjustment of the muscles and tendons is perfect according to the principles of mechanics. The muscles themselves possess a different property; they are irritable parts; motion originates in them. This living property of contraction is admirably suited, in each particular muscle, to the office it has to perform. In some it is suitable that the muscles should act as rapidly as the bowstring on the arrow; in others the action is slow and regular; in others it is irregular, and after long intervals, according as the functions to which they are subservient require. The motions of the limbs, the motions of the eye, those of the heart and arteries, stomach and bowels, are all different. This appropriation of action is not in the muscles themselves, but as they stand in relation to the nervous system, and the sensibilities which impel them.

We hope, then, by the course we have taken, that we have carried the reader to a higher sense of the perfection of the animal structure. We first drew him to observe provisions in the strengthening of the bones, the adjustment of their extremities to the joints, the course of the tendons, and other such mechanical appliances, proving to him the existence of intention in the formation of the solid fabric of the body. We have then explained how that motion is produced which was at all times familiar to him, but even the immediate causes of which he did not comprehend. We have, in the last place, shown him that under the term life he has a still more admirable subject of contemplation in the adjustment of those living properties; in the sensibilities differing not so much in degree as in kind; and in their appropriation, both to the operations of the internal economy, and to the relations external, and necessary to safety.

It is not possible to contemplate these things without having the full proof before us of the power of the Creator in forming and sustaining the animal body. As a man with *gutta serena* may turn his eyes to the sun, and feel no influence of light; so may the understanding be blind to these proofs; and we may say, with the celebrated Dr. Hunter, that he who can contemplate them without enthusiasm, must labour under a dead palsy in some part of his mind, and we must pity him as unfortunate.

CHAPTER IV.

OF THE CHANGES IN THE MATERIAL OF THE ANIMAL BODY DURING LIFE.

We have seen the motions performed in the animal body through the actions of the muscles and the play of the mechanical parts, and we have had occasion to reflect on the action of the heart and the motion of the blood in the circulation; but these are as nothing compared with the interest of our present subject—the changes going forward in the solid material of the frame. Is it not surprising that the individual who retains every peculiarity of body and of mind, whose features, whose gait and mode of action, whose voice, gestures, and complexion we are ready to attest as the very proof of personality, should in the course of a few days change every particle of his solid fabric?—that he whom we suppose we saw, is, as far as his body is concerned, a perfectly different person from him we now see? That the fluids may change we are ready to allow, but that the solids are thus ever shifting seems at first improbable. And yet, if there be any thing firmly established in physiology, if there be truth in the science at all, this fact is incontrovertible.

There is nothing like this in inanimate nature. It is beautiful to see the shooting of a crystal;—to note, first, the formation of integrant particles from their elements in solution, and these, assuming a regular form under the influence of attraction or crystalline polarity, producing a determinate shape; but the form is permanent. In the different processes of elective attraction, and in fermentation, we perceive a commotion, but in a little time the products are formed, and the particles are at rest. There is in these instances nothing like the revolutions of the living animal substance, where the material is alternately arranged and decomposed. The end of this is, that the machinery of the body is ever new, and possesses a property within itself of mending that which was broken, of throwing off that which was useless, and of building up that which was insecure and weak; of repelling disease, or of controlling it, and substituting what is healthful for that which is morbid. The whole animal machinery we have seen to be a thing fragile and exposed to injury; without this continual change of material, and this new modelling of that material, our lives would be more precarious; the texture of our bodies would be spoiled like some fine piece of mechanism which had stopped, and no workman would have science sufficient to reconstruct it. But by this process, the minute particles of the body die successively; not as in the final death of the whole body, but part by part is deprived of its vitality and taken away into the general circulation, whilst new parts are endowed with the property of life, and are built up in their place. By this revolution, we see nature, instead of having to establish a new mode of action for every casualty, heals all wounds, unites all broken bones, throws off all morbid parts by the continuance of its usual operations; and the surgeon who is modest in his calling, has nothing to do but to watch, lest ignorance or prejudice interfere with the process of nature. This property of the living body to restore itself when deranged, or to heal itself when broken or torn, is an action which so frequently assumes the appearance of reason, as if it were adapting itself to the particular occasion, that even the last great luminary in this science, Mr. John Hunter, speaks of parts of the body, as "conscious of their imperfection," and "acting from the stimulus of necessity," thus giving the properties of mind to the body, as the only explanation of phenomena so wonderful.

We make a moderate assumption, when we declare these changes to be under the guidance of the living principle. In a seed, or a nut, or an egg, we know that there is life, and from the length of time that these bodies

will remain without change, we are forced to acknowledge that this life is stationary or dormant, and limited to the counteraction of putrefaction or chemical decomposition; but no sooner does this principle become active, than a series of intestinal or internal changes are commenced, which are regularly progressive, without a moment's interruption, while life continues.

That principle which may continue an indefinite number of days, months, or years, producing no change in all this time, begins at once to exhibit its influence, builds up the individual body, regulates the actions of secretion and absorption; and, by its operation upon the material of the frame, stamps it with external marks of infancy, maturity, and age.

But let us examine the proofs of this universal change in the material of the body. It is not very long since a bone was supposed to be a concrete juice, and that the liquid parts were converted into solids, as we see mortar or Paris plaster from fluid assuming a solid form. But the anatomist began to observe, that the bones were porous; that these pores admitted membranes and vessels; and some went so far before their brethren, as to assert that they saw arteries, veins, lymphatics, and nerves going into the bone; in short, the opinion gradually grew stronger, that they were living parts, and subject to all the changes to which the softer parts of the living body were liable. An accident gave admirable proof of this. It was found that the bones of pigs, fed with the refuse of the dyer's vats, in which madder was contained, became tinged of a beautiful red colour. It was this fact which ingenious physiologists made use of, and which enabled them to demonstrate the rapidity with which the old bone was carried away, and new bone substituted. The physiologist observed, that if he threw a bone into the fire, what is called the animal part was burned and dissipated, but there remained, imperishable by this process, a mass of earth, which proved to be the phosphate of lime. He thought of varying his experiment, and put the bone into acid, which dissolved that phosphate of lime, and left the bone to all outward appearance as before. It had its form, its membranes, its vessels, but when pressed it proved to be soft and pliant; the phosphate of lime having been dissolved and extracted, it was no longer capable of the office of a bone, to bear the weight and motions of the body. When the experiments with madder were resumed, it appeared that when this earth of bone was about to be secreted from the circulating vessels, and deposited in the membranes of the bone, it met with the colouring particles of the madder in the blood; and, as the chemist would explain, the madder and the phosphate of lime were precipitated, and filled all the interstices of the membranes and vessels. We shall not stop here to inquire into the admirable manner in which this hardening material of bone is deposited for the purposes of strength—it is only the change upon the material which we have now to contemplate.

If this earth of bone, so coloured, had beeen deposited for a permanency, and built into these cells and crevices, like brick and mortar, the colour would remain; but, however deeply the bones of an animal may be tinged in this manner, the colour is not permanent, unless the animal continue to be fed with the madder. If its food be pure of the madder, even for a few weeks, and if after this the animal be killed, its bones are white, that is to say, the old particles of phosphate of lime are carried away by absorption, and with them the colouring material; and that newer bone which is deposited by the arteries is untinged and pure, having no colouring material to attract.

It is unnecessary to follow out those curious experiments by which the physiologist has shown the rapidity of the formation of a new bone around the broken end of an old one, and the deep tinge such new bone takes, compared with the fainter colour of that which had been perfect, previous to the feeding with madder; the manner in which, by feeding the animal alternately with madder and without it, he contrives to exhibit different coloured layers in the growing bone. It is sufficient for our purpose, to know that the densest part of the animal frame is subject to change, like the most delicate texture of the

body, and that the only means of arresting the motion is to deprive it of life; if a part of a bone be killed by the application of a cautery, that moment it becomes permanent, and is subject to no change, whilst all the parts around it are undergoing their revolutions.

The bones of the legs and thighs, which suffer the fatigue of motion, and which support the weight of the body, without diminishing in their length, or altering in the slightest measureable degree their proper form, are nevertheless undergoing an operation of repair, in which the old particles are withdrawn, whilst new ones replace them. We see with what care the walls of a house are shored up to admit of repair—how carefully the workman must estimate the strength of his pillars and beams—how nicely he must hammer in his wedges, that every interstice may be filled, and no strain permitted; and if this operation fail in the slightest degree, it is attended with a rent of the wall from top to bottom. We say, then, that by the very awkwardness of this process, in which, after all, there is danger of the whole fabric tumbling about the workmen, we are called upon to admire how the solid pillars in our own frame are a thousand times renewed, whilst the plan of the original fabric is followed to the utmost nicety in their restoration. And if it deviate at all, it is only in a manner the more to surprise us, since, on examination, it will be discovered to result from an adaptation of the strength of material to some new circumstance, the increasing weight it has to support, or the jar that it is subject to, from the change in the activity or exercise of the body.

There is a disease of the bone which illustrates this in a surprising manner, and proves to us, that however diseased and monstrous in its shape the bone may be, yet there is a natural law operating, which by its prevalence will overcome the morbid action, and from a shapeless mass restore the bone to its natural condition.

This disease is called *necrosis*, which word signifies the *death* of the bone merely; but it is death in very peculiar circumstances; a new bone is formed around the old one; a large and clumsy cylinder is fashioned of the earth of bone, in the hollow of which the shaft of the old bone is contained. After a long time the old bone comes out through this new case, and with the aid of the surgeon it is altogether withdrawn from the limb. During all this process the patient is capable of supporting his weight upon that limb, so that it resembles on a large scale that change which we have described as going continually on in the molecules of the bone; a new part is substituted, and the old taken away.

If workmen were to take away a pillar in the following manner, their work would resemble the process of necrosis: first, they must rear a hollow cylinder around the old pillar, resting on the plinth and base, and extending to the capital, and having secured the union of the cylinder at top and bottom to the extremities of the pillar, they must take away the shaft, or middle piece, of the old pillar by perforating the new cylinder.

The reader may easily imagine that when this process is completed in a man's limb, it will be as clumsy as the leg of an elephant, large, firm, and shapeless; but the extraordinary circumstance is still to be described.—This new bone is gradually diminished in its exterior surface, and its hollow filled up, and thus, by a change scarcely perceptible, it resumes the form and dimensions of the original bone; and, after a time, the anatomist might examine this limb and find neither in the articulating surfaces, nor in the spines and ridges, nor in the points of attachment for ligaments and muscles, any thing to indicate the extraordinary revolution that had taken place.

What explanation have we to give of this change? There can be no doubt that the material is not the same; for we have the old bone in our hand, and the man is walking upon a new bone. Yet extraordinary, then, as this appears, it is not more inexplicable than the common phenomenon of the growth of an infant to maturity. There is a living principle which is permanent while the material changes; and this principle attracts and arranges, dissolves and throws off successive portions of the solids. There is a law influencing this living principle, which, in its operation on the material, shapes and limits the growth of every part, and carries it through a regular series of changes, in which its form and aptness for its office are preserved, whilst the material alone is altered.

The influence of disease will for a time disorder this modelling process and produce tumours and distortions; but when at length the healthy action, that is, the natural action, prevails, these incumbrances are carried away, and the fair proportions of the fabric are restored.

It is very pleasing to observe the different means employed where a slight change of circumstances demands it. This earth of bone—the phosphate of lime—is changing continually; but the teeth admit of no change; they consist of earth too—the phosphate, carbonate, and fluate of lime. Bodies calculated for such violent attrition, and with a surface so hard as to strike fire with steel, would be ill accommodated with such a property of changing as we have seen in the bones. They must therefore fall out and be succeeded by new ones; and this process, familiar as it may be, is very curious when philosophically considered.

There are no teeth whilst yet the infant is at the breast; and when they rise they are attended with new appetites, and a necessity for change of food. When perfected they form a range of teeth, neat and small, adapted to the child's jaws and the size of its bones. Were they to grow at once, or to fall out at once, it would prove a disturbance to the act of eating. They fall in succession; their fangs are absorbed, they are loose and jangling, and are easily extracted. But now comes the question, why are these teeth of the infant old at six years? Why are those that are to succeed and be stationary for a series of years, to germinate and grow at the appointed time like the buds in the axilla of a leaf? And when fully formed, why do they remain perfect for sixty years instead of six; at the end of which term the first set were old and decayed? No difference can be observed in the material of the teeth of the first or second set. The one will be as perfect as the other after remaining a hundred years in a charnel house. Can any one refuse his belief, then, when he sees so accurate a mechanical adaptation of the teeth to their places and their offices; can he, we say, refuse assent to this also, that there is a law impressed—a property by which the milk teeth shall fail and be discharged from the jaw in six years, whilst the others will last the natural life of the adult, if not injured by accidents to which all parts are subject? This is not the only instance in which parts of the body lie dormant for a term of years, and are at a particular period of life developed and perfected—and which have, we may say, their time of infancy, perfection, and decay, whilst yet there is no material deterioration observable in the general frame.

We are thus brought to the consideration of a question which has not yet been fairly stated.

Those who say that life results from structure, and that the material is the ruling part, bid us look to the contrast of youth and age. The activity of limb and buoyancy of spirit they consider as a necessary consequence of the newness and perfection of organization in youth. On the other hand, a ruined tower, unroofed, and exposed to be broken up by alternation of frost and heat, dryness and moisture, wedged by the roots of ivy, and tottering to its fall, they compare with old age—with the shrunk limbs, tottering gait, shrivelled face, and scattered grey hair of the old.

But in all this there is not a word of truth. Whilst there is life and circulation there is change of the material of the frame (and there is a sign of this if a broken bone unites or a wound heals). Ascribe the distinction to the rapidity of change, to the velocity of circulation, or to the more or less energy of action; but with the antiquity of the material it can have nothing to do. The roundness and fulness of flesh, the smoothness, transparency, and colour of the cheek, belong to youth, as characteristic of the time of life, not as a necessary quality of the material! Is there a physiognomy in all nature—among birds and beasts, and insects and flowers—and

shall man alone have no indication of his condition in the outward form and character?

The distinctions in the body, apparent in the stages of life, have a deeper source than the accidental effects of the deterioration of the material of the frame. The same changes which are wrought on the structure of the body in youth and in the spring of life are going on in the last term of life; but the fabric is rebuilt on a different plan. The law of the formation is still inherent in the life which has hurried the material of the body through a succession of changes; and each stage, from the embryo to the fœtus, the fœtus to the child, from that to adolescence, to maturity, and to the condition of old age, has its outward form, as indicative of internal qualities, but not of the perfection or imperfection of the gross material. We might as well consider the difference in the term of life of the annual or biennial plant as compared with the oak, or the ephemeris fly as compared with the bird that hawks at it, to be in the qualities of the matter which forms them, as that the outward characters of the different stages of human life arose from the perfection or imperfection of the material of the body. Not only has every creature its appointed term of life, but we have shown that parts of the human body do not, in this respect, bear a relation to the whole; organs are changed and disappear; others, in the mean time, at their regulated period, shoot to perfection, and again decay before the failure of the body. What can more distinctly show that it is the principle of life that directs all; and that on it the law is imprinted which orders our formation, and all the revolutions we undergo? The material of the body, solid and fluid, is moved by this influence, and varies every day, part by part dying every hour, and renewed, until the series of its changes on the gross material of the body is accomplished in an entire and final separation.

The grand phenomena of nature make powerful impression on our imagination, and we acknowledge them to be under the guidance of Providence; but it is more pleasing, more agreeable to our self-importance, it gives us more confidence in that Providence, to discover that the minutest changes in nature are equally His care, and that "all things do homage."

Although it be true that every thing in nature, being philosophically contemplated, will lead to the same conclusions, yet the occurrences around us steal so imperceptibly on our observation, all the objects of nature, or at least vegetable and animal productions, grow up by so slow a process by our side, that we do not consider them at all in the same way as we should do if they started suddenly upon our vision.

It is this familiarity with the qualities of a living body, and a habit of seeing without reflection, which has made it necessary to carry the reader through so long a course of observation and reasoning to excite attention to the admirable structure of his own frame, and its adaptation to the earth we inhabit—to perceive that every thing is formed with a strict relation to the human faculties and organs, to extend our dominion and to multiply our sources of enjoyment. It is by seeing the plan of Providence in the establishment of relations between the condition of our being and the material world, that we learn to comprehend that unity of design in the creation in which we form so great a part.

This exaltation of our nature is not like the influence of pride or common ambition. We may use the words of Socrates to his scholar, who saw in the contemplation of nature only a proof of his own insignificance, and concluded "that the gods had no need of him," which drew this answer from the sage: "The greater the munificence they have shown in the care of thee, so much the more honour and service thou owest them!"

END OF VOLUME IV.

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