LIVING MECHANISMS BEFORE INVENTIONS

D. FRASER HARRIS

Professor of Physiology, Dalhousie University.

IT is quite surprising how many contrivances now used by man to effect certain mechanical or chemical ends had existed in animal bodies for aeons and aeons before *homo sapiens* appeared on this planet. It would seem as though his latest inventions for utilizing the forces of Nature or for overcoming the limits of time and space were merely more or less clever imitations of mechanisms already for countless ages in existence in living bodies.

To take his very latest triumph—the flying machine; it is, of course, the mechanical bird, although the earliest attempts at flying failed because they imitated the wings of birds too closely. A man does not possess a muscle sufficiently powerful to actuate a wing attached to his body after the fashion of the wing muscles of birds. The pectoral muscles of man are relatively far too feeble to cause an artificial wing fastened to his body to raise it off the earth. But, once he discovered a source of energy adequate to raising his weight into the air, the essence of the problem of flying was solved. The flying of a non-living mechanism is now an accomplished feat, but Nature had her living flying machines for untold ages before man's airplanes flew.

To take another example; man has only the other day contrived to travel in a totally submersible boat. He uses the principle of gas in varying states of compression to cause his subaqueous vessel to rise or sink, but this is precisely the principle employed by Nature in the mechanism of the swim-bladder of the fish. This bladder contains gas secreted into it from the blood, and there can be no question that the fish's buoyancy is related to the pressure of the gas in this sac. Increase of volume of the gas increases the fish's buoyancy, a decrease reduces it. Doubtless man did not consciously imitate the fish in constructing the submarine, but he unconsciously struck upon the same principle of floatation

Again, consider the phonograph or talking machine, for its name in plain English really describes it better than the more pompous Greek. What, exactly, has man contrived to do in this case? The answer is, to make a metallic or other membrane speak. This he has done by causing the membrane or diaphragm to vibrate in a manner wholly similar to that in which his own vocal cords vibrate when they initiate the process which ends in speaking. Aerial vibrations, emitted at a particular pitch, of a particular intensity and of a certain wave-form constitute the essence of speech, and it is just because the phonograph can emit vibrations having these characters that it can also speak. Nature's membrane vibrated many millenia before Edison's. In the telephone too, or that which "talks at a distance," the mechanism is again that of a vibrating membrane. No doubt the telephone is an electrically actuated membrane, but it vibrates, and that is all that the vocal cords really do. The analogies between the vocal apparatus and a wind instrument are very close. The vocal cords are the vibrating reeds, the trachea is the organ-pipe, the diaphragm is the bellows which, rising and falling, drives the air out of and sucks air into the wind-chest, the thorax.

Before we leave the non-living speaking mechanisms we might note that the principle of resonance is utilised in them as well as in the living body. The character and volume of our voice depend on the resonance by the air in the chest and back of the throat and in a number of other cavities in the bones of the head and face. The sound as produced by the vocal cords alone would be of a feeble, squeaking character, but when resonated by the air in the chest it is reinforced to such an extent that it becomes quite powerful and may acquire its characteristic quality. Now man has been able to employ this very principle of resonance in order to make his talking machines talk with something like human volume and quality. The wood of the case in which the phonograph is placed, as well as the trumpet or mouthpiece with which the earlier instruments were always provided, acts as a resonator to intensify the sound of the membrane of the sound-box. The human larynx is a reed instrument. In one of the reed pipes of the great organ man has contrived to imitate the capabilities of the larynx so well that the pipe has been called the *vox humana*.

The next form of energy we might study is that of light. We think that *we* have discovered for the first time in the world's history how to make of opaque materials that almost indispensable substance—glass—which is transparent to light. But, ages before mankind fused opaque materials to make glass, living Nature possessed two tissues, the cornea and the crystalline lens, both of them as transparent as the finest glass. The curious thing is that the cornea when viewed under the microscope is seen to be composed of tissue elements very similar to those which compose the skin or the tough, coarse "white" of the eye, and both cornea and lens *do* become opaque after death. The cornea is literally the window of the eye, the only transparent portion in its otherwise absolutely opaque coats.

The eye, from the optical point of view, is an instrument of exactly the same type as the photographic camera. The camera has a double convex lens to form a real, small, inverted image of external objects on a sensitive plate placed at a comparatively short distance behind the lens. The camera is blackened inside. The eye has a double convex lens which forms a real, small, inverted image of external objects upon a sensitive tissue, the retina, placed a short distance behind the lens. The eye also is blackened inside.

But this is not all. When the photographer wishes to sharpen the image on his ground glass plate, he puts in front of the lens what he calls "stops", diaphragms with circular apertures of varying sizes, the smallest of which gives the sharpest image. This he does because the lens possesses what physicists call "aberration of sphericity." Now in the eye there is exactly the same mechanism, namely, that of the iris, a circular curtain with a central circular aperture—the pupil—capable of having its size altered by nerves and muscles according to the amount of light falling on the eye. The pupil is small in bright, and large in feeble light. The lens of the eye also has spherical aberration. The iris of the eye, as a circular curtain capable of being closed or opened concentrically and with perfect symmetry of action, has been consciously copied in the diaphragm of the microscope. Here it is actually called an "iris diaphragm". It is found below the stage and above the condenser in a modern microscope. The analogies between eye and camera could hardly be closer. Lens, stop, sensitive plate, internal blackening to prevent internal reflections are all present in both the camera and the eye. Doubtless no man consciously copied the construction of the eye when devising the photographic camera or the camera obscura, but it is exceedingly remarkable that when man came to make an optical instrument to form an image of the outer world it should be found to correspond so closely to the construction of the eye, a living instrument designed for the very same purpose. These two—camera and eye—have one thing more in common, that of being able to adjust the focus for objects at different distances. In the camera this is managed by altering the distance between lens and plate, in the eye by the lens bulging forwards to become thicker at its centre and therefore a lens of shorter focus, which is exactly what is required. In old age, by diminished elasticity of the lens, near objects cannot be focussed at the same short distance at which they could in early life: this defect is called presbyopia, or the sight of old people.

The next form of energy we may consider is electricity. It needs no prolonged dissertation to point out the multitude of uses to which this form of energy is now put. We use it for lighting, heating and power, for communicating at a distance; we use it in curative medicine and in a thousand other ways. Few of us realize that all these applications of electricity to our daily wants, and indeed our knowledge of the first principles of the science, arose out of a controversy at the end of the eighteenth century between two Italians, Galvani and Volta, as to the reality of animal electricity itself.

Galvani, believing correctly in the existence of animal electricity and being criticised by Volta, who showed that certain cases of supposed electricity of animal origin were metallic in origin, devised many ingenious experiments to demonstrate electricity as arising in living tissues alone. Since his time electric currents have been found also in plant-tissues. It is now known that concomitantly with every activity of living protoplasm an electric current is generated, or at least a difference of potential between two related points is established. These "action-currents "are not difficult to demonstrate in muscle where electricity is one of the manifestations of kinetic energy, the other two being heat and external work.

In a nerve-fibre the electric disturbance is practically the only detectable manifestation of energy. The nerve-fibre acts pre-eminently as a conductor of nerve impulses, but these impulses as travelling in the conductor can be revealed only through their electrical counterparts. No doubt the voltage of these action currents in nerve is very small, but they are none the less electrical. The most striking example of electricity of animal origin is, of course, in the electric fishes, creatures which produce currents sufficiently powerful to kill their prey. It has been estimated that the most powerful of these discharges of electricity by fishes reaches an intensity of 200 volts. Aeons and aeons, then, before man discovered electricity and its adaptability to his numerous wants, Nature had been producing this same form of energy in her invisible living batteries. It has often been remarked, for example, how much the cross section of a submarine cable resembles that of a large nerve trunk. The nerve fibres are in fact Nature's living conductors or wires, and the one is insulated from the other in a manner wholly analogous to that of wires in a cable.

Turning now to mechanisms that are more purely physical, let us notice the simplest of these, the nail. Presumably man discovered at an early period of his history the simple and useful device of the nail or rivet for holding two pieces of board or metal together. In the living body the same device is used to fasten down the membrane covering the bone to the bone below. These fibres or living nails are known as "the perforating fibres of Sharpey" and are of fibrous tissue so calcified as to be literally "as hard as nails."

Another familiar device of the carpenter is dovetailing, as he calls it, or cutting the opposite edges of two boards in such a manner that they are made to interlock, and so cannot be pulled apart except by great violence. Nature uses this device in the so-called "serrated suture" or line of union of two flat bones, as in the flat bones of the cranium. The interlocking of the margins of the bones is so perfect that only by enormous force can they be separated, and then only by the complete destruction of the dovetailing.

There is scarcely a more familiar mechanism than that of the hinge. The hinge joint is a well known type of joint in the body, the elbow, wrist, knee, ankle and many others being all hinge joints. An equally familiar mechanism of human construction is the swivel or universal joint. The shoulder joint and the thigh joint are examples of swivel or ball-and-socket joints, so that Nature apparently did not feel constrained to confine herself to one type of bony articulation. The joint that "locks" and so prevents over-action is seen in the knee and elbow joints; in fact, the stork can go to sleep on one leg and not tumble over, largely because its knee joint locks so securely.

The next device we might notice, one used from remote antiquity, is that of the arch with its keystone. Bridges of this kind made by the Romans exist all over Europe. Now anatomists tell us that the plantar arch of the instep is precisely such an arch. It has a right and a left pier which support an arch of such immense strength, very largely because it is constructed on the keystone principle.

The pulley is a machine which one instinctively associates with human contriving, but the pulley was in use in the animal body ages before a pulley was ever made by man's hands. A pulley is essentially a device for altering the direction of action of a force. Pulleys are used in the animal body to enable a muscle which is not in the same straight line with its attachment to pull as though it were. The muscle is in one direction, the tendon in another, but by the tendon going over a pulley the muscle can literally pull round a corner. One of the muscles of the eye has this arrangement, also one of the muscles of the middle ear and several muscles of the foot. Of course the more complicated orders of pulley, where there are many sheaves in the block, are not found in the body. Nature attains her ends by the simplest means possible.

When, however, we come to levers we find that all the types of lever are used in animal mechanisms. In the first order of lever the fulcrum is between the power and the weight or resistance; in the second order the fulcrum is at the end of the lever beyond the resistance; in the third order the fulcrum is also at the end of the lever but is next the power. These, then, are the only possible orders of lever, and examples of all are found in the bodies of animals.

We use a lever of the first order when we nod the head; the fulcrum is at the joint between the head and spinal column, the weight of the head acts through the floor of the mouth, and the power is exerted by the deep muscles of the neck which pull on the back of the head. The relative arrangement of weight, fulcrum, and power is exactly as in the see-saw; when one child goes up the other goes down, so with the head; when the chin falls, the back of the head rises and *vice versa*. This first order is the lever of mechanical advantage. The way in which the foot is used to work the pedal of a harmonium or a sewing-machine is also an example of a lever of the first order. A pair of scissors is a double lever of this order.

The lever of the second order is used in the body when we stand on tiptoe. Here the fulcrum is the "balls" of the toes, the weight of the body passes through the plantar arch, and the power of the great hamstring muscles acts upwards from the heel bone. The whole body is raised by a group of its muscles. If the weight of the body be 150 lbs., then the calf muscles must exert a pull of about 90 lbs. to raise the body off the ground. This lever is the lever of power. The oar of a rowing boat acts as a lever of the second order, for the fulcrum is in the water, the weight is the boat, and the rower applies the power at the end of the oar. Nut-crackers and lemon-squeezers are examples of double levers of this order.

The lever of the third order is employed in a great many instances in the animal body. When we raise the hand towards the head we use it. The fulcrum is the elbow joint, the weight is the hand and anything it may contain, the power is applied by the biceps acting on the fore-arm beyond the fulcrum. This is the lever of rapidity of action; we use it when we wish to execute some action with maximum speed. When with extended arm and hand grasping a racquet we bring the arm swiftly forward to strike the ball, we use a lever of the third order; the effort expended is great, but what we lose in power we gain in speed. To raise one pound in the hand, we have to put forth an effort corresponding to 4 pounds near the elbow-joint. The sugar tongs is a double lever of the third order.

Related to the mechanisms of joints and muscles we might notice the catch-and-let-go mechanism which man has made use of. All instances of forces pent up, restrained, caught back and then suddenly let go are cases of this. It is the trigger mechanism; the coiled spring caught back and then let go to eject the harmless bullet of the child's pop-gun is an instance of it, the spring of Jack-in-the-box is another. Nature uses this catch-and-let-go or flicking mechanism every time a cheese maggot catches its tail by the front end of its body and then, suddenly straightening itself, lets go and leaps forward. These maggots have been photographed before, during, and after their flight. Every time we want to flick a paper pellet away from us or get rid of a piece of fluff on a coat we use this device. The bent finger, as is well known, is held back by the thumb, but all the time under strong muscular action. After an instant or two we release the finger suddenly, and it strikes the object we have in view far more forcibly than it could if merely extended without previous resistance.

It is when we come to valves in the body that we find man perhaps most completely forestalled.

We all know how absolutely indispensable are valves of one kind or another to the efficient working of the steam-engine and many other mechanical inventions. A valve is essentially a contrivance for permitting a flow of liquid or gas in one direction but not in the opposite. Water-pumps, air-pumps, and all machines which work on those principles depend entirely on the efficiency of the valves. The simplest type of valve is that found in the veins where two pouches opposite each other at certain intervals are so placed that the blood going to the heart can pass easily in that direction, but cannot reverse its stream because the attempt to do so closes the valves behind. More complicated are the valves in the interior of the heart where the flaps or cusps have special cords to keep the free borders from being forced too far back. The mechanism consists in the shortening of certain muscles inside the ventricles, and is comparable with that of a compensating pendulum whereby a movement in one direction is counteracted by an equal amount of movement in the opposite direction. Thus while blood can pass quite easily from auricle to ventricle, none of it can go in the opposite direction owing to the fact that in attempting to do so it closes the valves or doors behind it. At no fewer than four distinct places in the heart has Nature used this valvular mechanism; so anxious is she to permit a flow of blood only in one, the forward, direction.

The valves in the lymphatic vessels are exactly like those in veins. The mechanism of the valve is used for purposes other than preventing a back flow of blood or of lymph. It is used between the great and the small intestine to prevent the reflux of material from the one to the other. The valve in this case is a lipped valve with oblique entry. A similar valve is used in the bladder to prevent the ascent of urine from the bladder into the ureter, the duct of the kidney, whence it has descended. There is an analogous valvular arrangement in the larynx which prevents the escape of air from the chest when it is necessary to maintain an air-cushion in the chest in order to make very vigorous muscular exertions.

Hardly any machine is commoner than the pump, whether it be the force-pump or the suction-pump. Now the heart is alternately first the one and then the other. The ventricles of the heart are a force-pump when they are driving the blood out into the arteries; they are a suction-pump when they are dilating and sucking blood in from the veins close to them. More technically put, in the latter case they create a negative pressure in their interior with the result that the blood flows into them from the body veins where it is under a greater pressure. Negative pressure is utilised in a large number of machines of human contriving. Nature employs negative pressure in the organs of breathing in the following way; when it is necessary to get air into the lungs the walls of the chest rise somewhat rapidly, with the result that the air inside the lungs is rarified, a negative pressure is created and therefore outside air at atmospheric pressure at once flows into the lungs. Gases always move from places of higher to those of lower pressure. Of course the converse mechanism, that of creating in the lungs for a short time a pressure greater than the atmospheric, causes the impure air to leave the lungs.

Allied to the employment of negative pressure in animal mechanisms there is the principle of the boy's "sucker" to examine. This is a disc of leather which is pressed down on to a wet, smooth paving-stone on which it will slide about quite easily, but from which it cannot be pulled up by its string without considerable force. If the stone is loose, it can sometimes be lifted bodily up. The explanation is that a negative pressure has been created under the leather disc, so that it is pressed against the wet stone by the weight of the atmosphere. This principle is employed to keep the outer surface of the lung and the inner surface of the chest wall in contact, and yet permit perfect sliding movements between them.

The property of elasticity is of very great value in modern mechanical contrivances, but living bodies possessed elastic tissue untold ages before mankind discovered the numerous uses of india-rubber. Indiarubber, though the product of a living tree, is not itself alive. The elasticity of the coats of the arteries makes the pulse possible; if the arteries were rigid tubes, the rhythmic dilatation we call the pulse would not be possible. In certain diseases the arteries do become stiffened, and untoward results follow from a diminution of elasticity.

In some machines the elasticity of the spiral spring is utilised. The living body has its spiral springs in the shape of spirally coiled arteries. When the tissues are relatively collapsed these spirals are wound up; when the tissues become turgid, full, expanded, then the arteries are to some extent unwound, which could not happen if they had been constructed as simple, straight tubes. Being spirally wound they can be pulled out exactly as we pull out a piece of spirally wound electric wire. This device is used in the pregnant uterus.

The principle of the spring is used in quite another kind of manner, as, for instance, in the ligament which holds open the two halves or valves of an oyster shell. To close the shell the oyster uses a muscle (the adductor), so that when this muscle loses tone and dies the shell must of necessity lie open, since the spring of the ligament is not now antagonised by muscular action. In mechanisms of human devising this principle is employed in such cases as a spring to hold a door shut; we open the door by our muscular effort.

The opposite of this is inextensibility or extreme toughness. When we tie two things together with rope or with straps we do not want the ropes to stretch or "give". Living Nature frequently utilises the same principle when she unites two bones by a ligament, or a muscle to a bone by a tendon. These bands of tissue must not be capable of being stretched. They must hold the bones together, not rigidly, but without any yielding or stretching when movements are carried out by the bones. Ligaments entirely fulfil such conditions, for they are excessively tough and quite inextensible.

Animal elasticity is present in muscle for exactly the same reason that we find a spring interposed between the traces and the carriage, namely, to prevent a jar to the horse when he suddenly attempts to pull the carriage forward. When we suddenly contract our muscles, as we often need to, there would be an uncomfortable jar sent to the bones, were not the muscle possessed of some elasticity or "give". There is some "give" in the traces before the horse starts the carriage, and exactly the same mechanism is provided for by the presence of elasticity in muscles. But further, a healthy muscle is always tight or "taut" as sailors call it. The result of this is that the moment the muscle gets from its nerve the command to shorten, it is able to do so with the least possible delay. If the muscle were at all slack there would be time lost in pulling in the slack, but owing to the constant tightness this never occurs.

Even the idea of the inextensible outer cover over an inner tube is not something that mankind hit upon for the first time in the history of the universe. The distensible heart is covered by a tough, inelastic cover, the pericardium. Were it not for this tough cover the heart would easily and frequently be over-distended. The heart answers to the inner tube, the pericardium to the tough, outer tyre.

In most mechanical contrivances we wish friction reduced to a minimum; in a few we want some amount of friction retained. The animal body has examples of both these things. The surfaces of the cartilages, clothing the ends of bones in apposition at a joint, are not only exquisitely smooth, but moistened by a liquid which, containing a good deal of mucus, is as good a lubricant as oil. Nature uses this synovial fluid exactly where engineers use oil to reduce friction at bearings, etc.; and when in disease this liquid dries up then the joints creak and grate exactly like the hinges of a door in need of oiling.

Sometimes the opposite effect is desired. For instance, when the chemist wants to grind up some very slimy or slippery material with his pestle and mortar, he throws in some clean sand or powdered glass in order to make the pestle catch or grip the substance to be crushed. Here he desires friction, and it is supplied by the gritty particles of the sand. But, ages before the chemist hit on this, Nature had arranged that certain birds should retain stones in their gizzards or muscular stomachs in order that the smooth grains should be able to be grasped by the very smooth, horny walls of the gizzard, and so be ground up as fine as possible.

We have thus seen how remarkably mankind has been forestalled in the matter of the principles utilised in a large number of machines; transparent tissues, lenses, iris diaphragms, optical images, photo-sensitive surfaces, pulleys, levers, valves, pumps, the use of negative pressure, elasticity, coiled springs, buoyancy and electric energy, were all in use in animal bodies millions and millions of ages before man himself appeared on this planet. When in the fulness of time he did appear, and laboriously learned to construct machines to do work for him, he was merely discovering principles but not inventing them. The devices had been in existence for countless millenia before he thought and worked, so that in this sense indeed there is nothing new under the sun.

THE CHOICE OF MOSES

REV. A. L. FRASER

Grave and thought-burdened, ere his noon of day,
His stairs he climbed, and in the distance viewed
The countless tents where o'er-wrought Slavery lay,
And wondered if the stream of Promise would
End like a river in the fruitless sand.
Self bade him close his eyes; but Jochebed,
Pale, thin and worn, before him seemed to stand.
And all his early dreams rose from the dead.

Then as he left, bidding the place good-bye,
He crossed Fame's doorway, though he knew it not.
Life could not be—to eat, play, sleep, and die;
So, while those jewelled courtiers are forgot,
To him the centuries have gone to school,
Where priests have learned to worship, kings to rule.