MAN AS A MACHINE.

HUMAN ENERGY AND ITS EXPENDITURE.

BY DR. H. DEKKER.

In 1748 the French physician La Mettrie published a book in which he attempted to prove that man is nothing but a machine, and the attempt has since been repeated by countless writers. But not to speak of finer differences between men and machines, no machine is born of or gives birth to another machine, grows, reproduces its worn-out substance, or is able to adapt itself to altered conditions. The function of a steam engine is to convert latent energy into motion. This statement is equally true of human muscles, but while the production of motion of one particular kind exhausts the powers of the engine, the human muscles can produce motion of many kinds and do a great many other things. Steam engines and similar machines are unconscious and imperfect imitations of the muscular machine, which is the natural transformer of energy. The artificial machine consumes coal, the natural machine consumes food, or, more specifically, glycogen, the starch-like substance which the liver manufactures from the food. In the words of Bruecke, a muscle is an engine built of albumen and stoked with glycogen. Both machines consume oxygen and generate heat.

A question of prime importance, both in the operation of machinery and in the activities of living beings, is this: How can a given task be accomplished with the smallest expenditure of energy? For expenditure of energy means expenditure of fuel or food. There are two ways in which economical utilization of energy may be sought: in the construction of the machine, and in its operation.

In general, the moving parts of machines are made as light as possible not only in order to save material and energy, but also in order to minimize the disturbing and disintegrating effects of vibration, but certain parts, such as the rims of fly wheels, are purposely made heavy in order to insure steadiness of motion through their inertia. The same principle finds expression in the thickening of the lower part of the leg bone in such fleet-footed animals as horses, camels, and ostriches. The bones are composed of a solid, but elastic, material, in which a saving is effected wherever this is possible. Their internal structure satisfies theoretical requirements more fully than that of the materials of artificial machines.

Nearly half the weight of the human body consists of muscles, which connect the bones and, by contraction, move them into various positions. In the best steam engines only one-tenth of the potential energy of the fuel is converted into mechanical work, but the muscles utilize in work from 34 to 55 per cent of the energy of the food—and probably much more, as the experiments which furnished these figures were performed with muscles removed from the body, not with living muscle, richly supplied with blood. The less the contraction of a muscle, the greater is its efficiency, or economy.

Most muscular movements are voluntary and may consequently be performed in an economical or a wasteful manner, at will. And we shall see that we are, even in health, very sparing of energy. Rheumatic persons are forced by the pain inflicted by violent movements, and convalescents and anæmic and neurasthenic persons are compelled by fatigue, to be positively niggardly. From the slow and cautious movements of such invalids we may learn how to execute a given movement with the smallest expenditure of energy. On the other hand, children are prodigal of energy, because their muscles need to be developed and educated by exercise.

A steam engine which is kept in good condition works hour after hour and day after day, always consuming the same quantity of coal in performing the same amount of work. This is not the case with the muscles, for the waste products of combustion accumulate in them and cause fatigue. This poison of fatigue is gradually washed away by the blood. In light and slow work it is carried off as rapidly as it is formed by the activity of the muscle, but in heavy, violent, or greatly prolonged labor it accumulates in the muscles and makes them less efficient as machines, so that they consume more fuel in performing a given amount of work. It is the sensation of fatigue that causes us unconsciously to select the easiest way of doing things—for example, to ascend a mountain by a winding, rather than by a straight, road, although we thus increase the total amount of work.

Haughton cites a very interesting case in his "Principles of Animal Mechanics." The women of a seaside village *A* (Fig. 4) were accustomed to go to a point *B* on the beach, for mussels. The way lay partly over solid ground, partly through a swamp in which progress was slow and laborious. A child would probably have taken the shortest course, the straight line *AB*, more than half of which lies through the swamp, and an invalid would have chosen the course *ACB*, in which the distance to be traversed on soft ground is reduced to the minimum. The mussel gatherers selected the intermediate course *ADB*. Haughton measured the angles *a* and *b*, which the two parts of their course make with a line drawn at right angles to the edge of the swamp, and determined the speeds *v* and *v*¹, at which the women walked over the solid ground and the swamp. He found that these quantities satisfied the equation:

$$\frac{\sin a}{\sin b} = \frac{v}{v^1}$$

Now this is the fundamental law of the refraction of light. In other words, if the solid ground and the swamp are taken to represent two media in which the velocities of light are *v* and *v*¹, a ray of light going from *A* to *B* would follow the path taken by the women. This is the path by which the goal is reached in the shortest time and also with the smallest expenditure of energy. The mussel gatherers found this path, not by mathematical reasoning, but by experience.

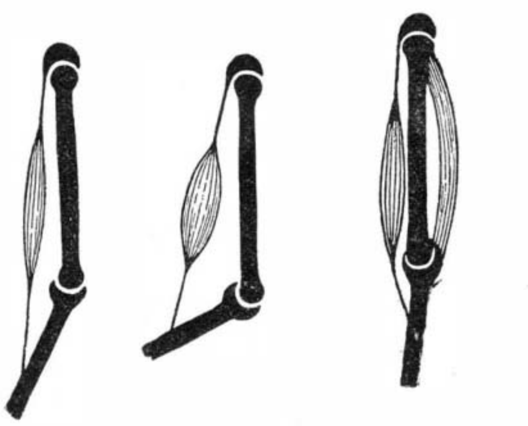

FIG. 1.—A MUSCLE AT REST. FIG. 2.—A MUSCLE IN ACTION. FIG. 3.—A PAIR OF "ANTAGONISTIC" MUSCLES.

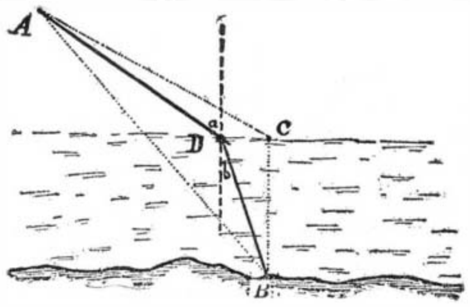

FIG. 4.—DIAGRAM OF THE MUSSEL GATHERERS.

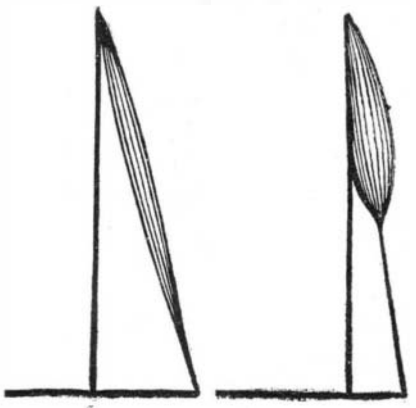

FIG. 5.—MAREY'S EXPERIMENT.

Before the operation. After the operation.

So, too, in work which involves movement of only part of the body, as in driving a nail, lifting a weight, etc., experience teaches us to select the easiest method. An inspection of Figs. 1 and 2 will make it evident that a muscle produces the maximum effect when the bones which it connects are at right angles to each other. Advantage is taken of this fact in bowling, exercising on the horizontal bars, etc.

There is another method of economizing muscular energy. When we undertake any task for the first time, we set to work, in addition to the muscles which must be used, other muscles, the activity of which is useless or even a hindrance. Thus we waste energy and quickly become fatigued. By practice, however, we learn to employ only the required muscles and so to reduce our exertion to a minimum. A child learning to write wastes its strength in gripping the pencil with unnecessary force. A boy learning to ride the bicycle holds the handle bars so firmly that his arms become tired sooner than his legs. By practice, the art of performing any action with the smallest exertion is acquired quite unconsciously. The guiding principle is the feeling of fatigue. No preliminary study of anatomy and mechanics would diminish the number of falls experienced while learning to ride the bicycle.

The movements of walking and running are too complex to be completely discussed here, but it may be observed that most persons who are not invalids waste much energy in raising the body unnecessarily with each step, and that in running exertion is saved by the bent positions of the knees and the body.

Every bodily movement calls a number of muscles into action, and the action of every muscle is opposed by another muscle, or group of muscles. The flexor and extensor muscles of the arm are examples (Fig. 3). When the arm hangs limp both the flexor muscle at the front of the upper arm and the extensor muscle at the back are soft, but both stiffen and contract when a weight is placed in the hand. The effect of this contraction is to hold the elbow joint in place. There are no loose joints in artificial machines. The joint of a pair of compasses, for example, is tightened by a special device, but no such devices are found in the joints of the body. In the construction of machines care is taken to produce certain motions as accurately as possible and to prevent "lost motion." For this purpose bearings, pivots, rails, and guides of various forms are employed. Motion of this character is called "constrained motion." But in the elbow joint precision of movement is attained, not by constraint imposed by solid bearings and guides, but by muscular tension. The same expedient is employed in machinery, but rarely, as it involves waste of energy. Is nature, then, wasteful of energy? No; for if all the motions of the body were constrained, a multitude of bony structures would be required which would overload the body and demand nourishment even when not in use. Hence it is more economical to secure precision of movement, when this is necessary, by muscular effort. Moreover, the tension joint permits a certain freedom of movement which is required for the thousand daily needs of the body, while the constrained machine is designed to execute a single movement with the greatest possible precision.

Two "antagonistic" muscles, such as the flexor and extensor of the arm, do not always work together, as in the case of the weight held with the arm pendent. When the arm is bent slowly both muscles act, for here, again, the elbow joint must be kept firmly in place, but when the arm is bent quickly the extensor muscle (at the back of the arm) does not come into action until the completion of the movement, which it arrests. The eyeball presents one of the few instances of constrained motion in the human body. The eye is turned outward and inward by two antagonistic muscles, but when it is turned outward by the contraction of the outer muscle, the inner muscle neither contracts to oppose the motion, nor remains passive, but spontaneously elongates. We see, then, that whenever muscular tension is required to steady a joint, at rest or in slow movement, the antagonistic muscles act together, but in rapid and in constrained movements the waste of energy involved in their simultaneous action is avoided.

The force exerted by a muscle increases with the number of muscular fibers which it contains, or with its sectional area. The tensile strength of human muscle is more than 140 pounds per square inch. The extent to which a muscle can contract is proportional to its length. It has been proved by anatomical study and experiment that the length and thickness of each muscle are exactly adapted to the work required of that muscle. If the work is increased, the muscle increases in proportion. Examples of this are seen in the arm of the blacksmith and the calf of the ballet dancer. If necessary, the length of the muscle increases as well as its thickness, and in some cases the length diminishes. For example, if a limb is shortened by the removal of a diseased portion of

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bone and the union of the remaining parts, the muscles gradually decrease in length until they are again able to perform their normal functions.

In a similar manner the relative lengths of a muscle and its attached tendon may be altered by adaptation to changed conditions. The rotation of the forearm about its axis is effected by a flat muscle which runs obliquely from the elbow to a point on the radius (the smaller bone of the forearm). When this rotation has become limited through a stiffening of the elbow joint or otherwise, so that the whole length of the rotating muscle can no longer be utilized, part of it becomes converted into tendon. Marey removed part of the heel bone of a rabbit and attached the stump to the tendon of the muscle of the leg. The muscle now acted on a shorter lever and consequently was required to exert a greater force, but to contract to a smaller extent, than before the operation. The consequence was that the muscle became shorter and thicker, and its tendon increased in length (Fig. 5). The dimensions and shape of every muscle and the length of its tendon are adapted to its work with a perfection never attained in artificial machines.

We have seen that the muscles utilize more than half the energy supplied to them and that they work most economically when they contract but slightly. We do not know how the chemical energy of glycogen (and possibly also of fat) is transformed into external work. We know, however, that five times as much blood flows through a muscle at work than flows through the same muscle at rest, and that the working muscle consumes 20 times as much oxygen and 35 times as much carbon as the idle muscle consumes in the same time. We know also that heat is produced as well as work. Heidenhain has discovered that, within certain limits, the work performed by a muscle increases with the amount of work demanded of it, and that less heat, relatively, is developed by intense than by moderate muscular activity. This is an admirable provision for economy in heat and energy.

In everything pertaining to the body, its external form, the adaptation of its members for the performance of work, the internal construction of the muscular machine, and the operation of all its parts, we find examples of economy and fitness which the machine designer might study with profit.—Translated for the SCIENTIFIC AMERICAN SUPPLEMENT from Kosmos.

THE COALFIELDS OF THE UNITED STATES.*

2,000 BILLION TONS OF COAL AVAILABLE.

THE COALFIELDS OF THE UNITED STATES.

THE accompanying map, redrawn from one prepared by the United States Geological Survey, shows the coalfields of the United States as their outline is now known and the kinds of coal they contain. Up to the present time it has not been possible to prepare so accurate a map, on account of lack of data regarding the shape and extent of many of the western coalfields and the quality of their coal, but during the last few years a large amount of such information has been obtained in connection with the classification and valuation of coal land in the public land States of the West. In carrying on this work the Geological Survey has mapped most of the important coalfields and has tested many of the coals, so that information now at hand seems to be fairly complete. There is still, however, considerable uncertainty regarding the extent and value of some fields containing low-grade coal or lignite. This is particularly true of the lignite fields of the Gulf province, except those of Texas, in which there has been considerable development and exploitation. Little information is available regarding the lignite areas of South Dakota and the lignite and sub-bituminous fields of the Fort Union region, in eastern Montana. The extent and value of the coal beds of the Assiniboine region, in north central Montana, as well as those of the isolated Tertiary lake basins of the mountainous parts of the State, are also matters of speculation.

Information as to the extent, the value, and even the existence of the coalfields of the Pacific coast is very meager. California and Oregon probably have greater coal resources than those now known, but the beds in these States are generally of low-grade coal and are undeveloped. The fields of Washington doubtless embrace a much greater area than that shown on the map, but they are so covered by glacial gravel and heavy timber that it is impossible to determine their extent. Probably many of the areas represented on the map are really connected in a broad belt of coal-bearing rocks along the west slope of the Cascade range.

Little is known regarding the occurrence of coal or the extent of the fields in southern and southeastern Utah, where there are probably many areas of coal-bearing rocks but little coal of commercial importance.

On this map, for the first time, an attempt has been made to represent the coal in the deep basins or synclines of the Rocky Mountain States, where there is every reason to suppose that coal exists, although it is so deeply covered by later sediments as to be accessible with great difficulty if at all. The most important of these basins are the San Juan River basin of New Mexico and the Colorado, the Uinta basin of Colorado and Utah, the Green River basin of Wyoming and Colorado, and the Bighorn basin of Wyoming. None of the basins and troughs of the eastern part of the country is like these western basins, except possibly, the central part of the Appalachian trough in West Virginia and a part of the Michigan basin, but both of these are comparatively shallow, and all of the coal they contain may be regarded as accessible.

CHARACTER OF THE COALS.

From a commercial standpoint the most important feature of the map is the distinction between the various grades of coal. The Geological Survey recognizes the following six classes: (1) anthracite, (2) semi-anthracite, (3) semi-bituminous, (4) bituminous, (5) sub-bituminous (black lignite), and (6) lignite.

In almost all the western fields there is a transition from low-grade to high-grade coal in the direction of the principal mountain uplift. In the San Juan River region the coal changes from sub-bituminous in the southern part to bituminous on the flanks of the San Juan Mountains, the transition in the field being gradual and not sharp. In the Uinta basin the coal is bituminous, and of fairly uniform quality in all parts of the rim. In the Green River basin most of the coal is sub-bituminous, but some around the

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