II.

THE ANIMAL AS A MACHINE AND A PRIME MOTOR.

13. **The Animal as a Machine.**—The engineer regards the animal system with peculiar interest, as a machine of singularly complicated structure, a heat-engine or other prime motor—he is not certain as to its classification—of extraordinary efficiency, and as the embodiment of scientific problems of the highest interest and greatest obscurity. In this curious machine, combustible matter in the form of the grains or other foods, is consumed, with resultant production of carbon dioxide and other chemical compounds of various degrees of oxidation, and there is thus made available thermal, mechanical, and probably electrical as well as vital energies, all of which energies find application in the processes of animal life, in the performance of work, external and internal, and probably in mental operations as well. Waste also occurs in the form of heat and the rejected potential energy of incomplete chemical action.

Considering the automatic system of the animal, apart from intelligence and will, it is, in the eye of the engineer, a self-contained prime mover, including its furnace, its mechanism of work and energy-development, and possessing mechanism of transmission of power peculiarly and exactly adapted to its purposes.

14. The Animal as a Prime Motor.*—Hirn was probably the first and the greatest of those who have sought to measure up the energies of living creatures, and to follow the transformations which occur in the processes of vital organization and animal exertion.†

The origin of heat in the bodies of living animals has been a matter awakening the greatest interest and curiosity from the earliest times. The ancients thought heat and light a part of the vital power, due to the creative act, and without immediate source in the processes of vital existence. They thought the act of breathing a necessary process of cooling and removal of excess of this spontaneously generated heat, due to the fact of life simply. Since the establishment of the principles of energy in modern times, however, the philosopher has only concerned himself as to the method of production of this heat, recognizing the fact that it must have its origin, as must all the exhibitions and expenditures of energy that accompany it in the living being, from the potential and latent energies of combustible substances subjected to the processes of digestion and assimilation in the body. The scientific man of later times sees in the vital processes a transformation of energies originating in a slow combustion at low temperature, with changes of form of the resulting energies which, though none the less certainly phases of the chain of vital phenomena which he studies, are not all fully understood, or as yet all detected and rendered evident by research. The chemical compositions of these combustibles are

* From Cassier's Magazine, Feb., 1892; by R. H. Thurston.

† La Thermodynamique et l'Étude du Travail chez les Êtres vivants. G. A. Hirn, Paris. *Bureaux des Revues*, 1887.

known; the quantities of energy which may be obtained by their perfect combustion to carbonic acid and water are well ascertained, and it only remains to determine the exact nature of the processes by which it is possible to effect their combustion at the temperature of the animal system, and to utilize by transformation the resulting power through those intermediate forms of energy-change which remain as yet undiscovered, and, in that sense, mysterious. We do not yet know how to produce combustion at a temperature of 98° Fahr., that at which combustion certainly does occur in the human system; or at the still lower temperatures at which such chemical changes go on in the bodies of cold-blooded creatures; nor do we know how to secure transformation of heat into mechanical and other forms of energy without sensible change of temperature and with high efficiency. In all our uses of heat-engines the wastes are a much greater proportion of the available energy than in any animal system, except where, as in some cases of application of the heat-energy of steam, for example, the wastes of the engine are, as in the human body, utilized for heating purposes.

The muscles when doing work, and all the glands, every organ, in fact, while performing its legitimate function, is found to become warmer; indicating the final appearance of whatever form of energy may be operating in the system in the form of heat. Heat is produced, apparently, in all the organs of the body, but in different degree, accordingly as their action is intense or deliberate. Those veins which return blood from working organs bring it back slightly warmer than the average for the whole system; those coming in toward the heart from the skin bring back colder blood from that constantly refrigerated system of capillaries. The mean temperature of the venous blood entering the heart is about one degree warmer, in man, than the average for the whole system; between one and two degrees warmer than the arterial blood. The temperature of the body, as a whole, is automatically regulated by the system of nerves studied by Bernard; which causes the flow of blood toward any part to be accelerated when that part is cold, and retarded when it is too warm.

In every mechanism endowed with animal life, heat is produced and work is performed. It by no means follows that the work is the result of thermodynamic transformation; in fact, it seems impossible, in view of the fact that we have in the animal system no differences of temperature such as characterize and limit the action of the thermodynamic engine, that there should be a thermodynamic transformation. The heat would seem to be either a "by-product" or to be produced simply to insure uniform and sufficient temperature to permit the continuous and steady action of the vital powers and the machinery of the body. All the alimentary substances are combustible; but it is not a necessary consequence that they should be oxidized by a heat-producing combustion within the animal system. On the contrary, the quantity of heat which would be thus produced, added to the quantity of work performed by the vital organs, in digestion, nutrition, circulation of the blood,—itself an enormous quantity,—though reproducing the energy thus expended, as heat, and thus, in one sense, costing nothing—and in brain-work, to say nothing of wastes by conduction and radiation to surrounding objects, the total amount of heat produced by such combustion would vastly exceed the quantity discharged from the body in any given time. This discrepancy is greater in cold-blooded animals than in warm-blooded; and, in many instances, the heat given out is probably too small in amount to account for combustion of any important fraction of the aliment of the system. The animal machine is not thermodynamic in the usual acceptation of that term, even if it be in any sense.

Mon. J. Beclard was probably the first to attempt to measure the relation of quantity and of transformation, thermodynamically, if such energy-transformations actually occur, in the animal machine. But he reached no definite result. Herdenheim suceeded little better; but Hirn found ways of investigation which gave real quantitative results of importance. A certain correspondence was found between work performed and heat exhaled; but nothing in his experiments gave indications of the method of production of that heat; and it is still impossible to say whether the heat is the direct product of oxidation of food, the result of oxidation of worn muscular and other tissue, or due to a number of thermal and other interactions occurring within the body and as yet beyond the reach of scientific observation. The disappearance of heat unquestionably established by Hirn's researches may or may not have been due to thermodynamic transformations. Whatever form of energy-transformation characterizes the vital machine, the wastes of energy take the final form of heat, and its quantity would, in any case, be reduced by the production of mechanical energy and the performance of work within and without the body.

In 1856–57 Hirn experimented with men engaged in regular work and at rest, and found that when at rest they produced a quantity of heat almost exactly, if not precisely, proportional to the amount of oxidation, as measured by the quantity of oxygen absorbed by them and exhaled in carbonic acid.

This was not precisely the case when they were at work. The principle of equivalence of energies then takes effect, and the measure of all the energy produced by oxidation is found in the sum of the heat discharged from the system and that energy of work which stands for the parts converted into dynamic forms.*

Hirn found that the quantity of heat generated by the human body at rest, whether that of men of middle age, or youth of either sex approaching maturity, was substantially the same under the same circumstances: about 5 calories per gramme of oxygen inspired and exhaled as a minimum, 5.2 as a maximum, and usually the latter figure. The differences may be ascribed to variations in observations, rather than to real differences of fact. Precisely the same quantities of air were measured as exhaled as were measured as inhaled, in all cases. A singular and significant fact was, however. discoverable in the results, as reported by Hirn: The quantity of heat produced per unit of oxygen absorbed and converted into compounds exceeds by a third the amount computed upon the basis of the experiments of Favre and Silbermann. This result would seem to indicate other sources of heat than combustion with oxygen. It may be due to

* L'Équivalent mécanique de la Chaleur. G. A. Hirn, 1858.

oxygen absorbed and exhaled through the skin ; to the conversion of stored energies as yet undetected in the system, or to the combination of other elements, as carbon and hydrogen, through processes resulting in the production of heat.* It is to the latter cause that Hirn would ascribe this excess of exhaled energy. This subject remains still to be investigated.

The same individuals being set at hard work in a treadmill constructed for the purpose, in such manner as give the figures for a normal condition of labor, unforced but steady, and at a maximum for a day's work, gave out but about one half as much heat per unit of air breathed and of oxygen consumed, showing clearly the transformation of heat into work. The efficiencies of the human system, considered as a heat-motor or -engine, ranged, according to the condition and temperament of the subject of the test, from 17 per cent to 25 per cent when raising the load or themselves ascending, and rose to 30 and 40 per cent in descent. A lymphatic youth of 18 gave the lowest figures; a strong man of 47 the highest. These results all exceed those obtainable as yet from the most economical forms of existing gas- or steam-engine, in which 20 per cent may be taken as about the contemporary limit of their efficiency as heat-engines.

To fully secure this efficiency in the human body as a heat-engine subjected to the accepted laws of thermodynamics would demand a temperature within its working parts not far from 140 Cent. (284° Fahr.), or far above the boiling-point of water. This fact is crucial as a proof that the transformations of energy

* See Sarason : *Revue Scientifique*, 1887, page 306 *et seq.*

in the animal system are not, in the accepted sense, thermo-dynamic. They must involve as yet unknown processes and methods, and must be free from the control of thermodynamic principles, as we are accustomed to denominate them. The "second law of thermo-dynamics" is here evaded.

In those cases in which work was done, the production of heat was as much less than that anticipated, as computed from the engineers' and the physicists' experiments, as, in the case of rest, that figure was exceeded, falling in the latter case to from 2.5 calories to 3.5 per gramme, varying with the individual and his familiarity with the work, and consequent efficiency as a machine.

Thus the investigator shows that while the animal system is unquestionably a machine producing and utilizing energy by transformation, it possesses some peculiarities and conceals some secrets that science has still to discover through exact methods of research. It further has become evident that these methods of production and utilization of energy include some which are very different from those familiar to us, as exhibited in our inanimate heat-engines, and which, once discovered and given application, should that prove practicable in artificial machines of this class, will probably prove enormously advantageous in the saving of costly energies now so largely wasted. Could we discover and apply these methods in displacing our heat-engines, it would give us direct transformations of energy into work at low temperatures, with little or no wastes, and thus enormously extend the period of human life on this globe, as well as its productiveness. It will be an interesting question for the electrician and the engineer to settle: whether these as yet mysterious processes are not electro-dynamic or related phenomena.

15. **The Processes of the Vital Machines** employed in the development of power result mysteriously in the production of heat, light, electricity, and dynamic energy by methods still unknown, and with an efficiency of development, transformation, and application frequently, if not always, much greater than has been yet attained by any of the machines devised by man to effect similar results. Mechanical power is exerted at less cost in potential energy supplied than in the steam-engine; heat is evolved as the product of combustion or other action at a low temperature, and with insignificant waste by non-utilization in the processes of the animal economy; light is produced by glow-worms and fire-flies without sensible loss in accompanying thermal or other energy; and electricity, probably the motor energy of the machine, is produced with similar wonderful economy by processes of which we have no knowledge. Combustion at ordinary low temperatures, in the tissues of the body; chemical combinations of other kinds in the digestive organs, by the action of peptic substances in solution in the fluids of the system, and other processes unknown, as yet: these evade the inevitable losses of thermo-dynamic operations in the vital machine, and effect results which are never economically obtainable by the machines of the inventor and mechanic. These constitute a standing riddle and challenge to the man of science and the engineer.

Lavoisier, as early as 1789, asserted that animals are composed of combustible substances, and that their life is based upon chemical action involving the slow combustion of the carbon and hydrogen of their food and muscle; respiration furnishing the needed oxygen—an element discovered by him three years earlier. Rumford, in 1797, stated that animals, considered as machines, were efficient prime motors, and in 1799 published his discovery of the identity of heat with mechanical energy and his approximation to the value of the mechanical equivalent; and Scoresby and Joule, and especially Hirn, later completely confirmed his views on these points.*

Modern research shows that the evolution of heat is at least an invariable accompaniment of all action of the animal system—also even of the brain and spinal cord. Thought and manual labor, in the case of the human machine, are alike productive of increased temperature and of accelerated exhalation of carbon dioxide from the lungs and of salts from other organs. Whether these chemical actions are direct results or simply incidental to intermediate transformations of matter and energy is as yet not fully determined. The effect of exercise is invariably to increase greatly the consumption of oxygen, and the elimination of carbon dioxide, and the temperature of the body, within narrow limits; regulation being effected by exudation of perspiration and its evaporation. Other effects of increased exertion of the muscular system are the promotion of digestion, the consumption of accumulated combustible matter, as the fats, and increased rapidity and thoroughness of blood circulation and of nutrition,

* On these points, see Seguin and Lavoisier (Premier Mémoir), Rumford's Essays, and *Philosophical Magazine*, 1846.

which are the essentials to efficient action of the machine as a whole. The wonderful self-adjusting power of the system makes these actions effective even locally; and the exercise of one member or part of the machine produces increased circulation, increased degeneration, and at the same time increased blood-supply and nutrition of the part thus compelled to supply energy.

The muscular system constitutes about 40 per cent of the weight of the body, and contains blood to the amount of one third this weight, or 12 to 15 per cent of the whole weight of the body. The wear of this muscular tissue gives rise to a demand for the nitrogenous foods to supply the waste, and thus produces an appetite for lean meats or for vegetable foods rich in gluten. The nervous tissue, the system of intercommunication and transfer of energy from part to part, is also subject to wear; and this waste is supplied by the phosphatic foods, as animal brain, marrow, nerve, and glandular or other white meats, and as the fruits and the grain-foods, the peculiar diet of the human and especially of the brain-working creature. Overuse of the muscles or of the nervous system reduces their powers of recuperation, repair, and general nutrition; and it is for this reason that labor and exercise should be carefully restricted within those limits marked by the appearance of symptoms of exhaustion. Highest efficiency of the animal, as of any other machine, can be permanently maintained only when the conditions of maximum perfection of parts and of operation are ascertained and insured. The selection of proper foods is as essential to the successful maintenance and use of the animal machine as the securing of good fuel for use in the heat-engines; attention to diet and the adjustment of the periods of employment to best effect are as important as the supply of the best coal and the periodical stoppage and repair of the machinery in a mill or factory.

The elimination of nitrogen and carbon dioxide is, in some as yet uncertain way, a gauge of the quantity of useful and lost work of the animal machine. Liebig states in his Animal Chemistry (1843) that the excretion of nitrogen is proportional to the destruction of tissue, and Lehman states in his turn that he finds this excretion increased by exercise. Fick and Wislicenus, on the other hand, assert that the animal is a heat-engine, and that the performance of work affects the elimination of nitrogen slightly, but increases that of carbon dioxide enormously, and this view is confirmed by Frankland and by Houghton; while Dr. Parkes indirectly gives similar testimony in the statement that work is done by the consumption of other than nitrogenous foods, the elimination of nitrogen being due to waste of tissue; that of carbonic acid to combustion resulting in thermodynamic action. Incidentally, Liebig also confirms this idea by his statement that the exhalation of nitrogen goes on long after work has ceased.* Dr. Pavy, on the other hand, found by experiment on two well-known pedestrians that their excessive exertion produced greatly increased elimination of nitrogen—apparently a consequence of the breaking down of tissue. He concludes that the body is a true heat-engine, but he finds it capable apparently

*See Frankland's Origin of Muscular Power; Houghton in the *Lancet*, 1868.; Parkes in the *Medical Times*, 1871; Flint on Muscular Power, 1872.; Pavy on Muscular Power, 1878.

of performing more work than the food would seem competent to do. In these cases it would seem very possible that the observed excess may come of consumption of tissue in addition to food; the waste being gradually repaired during a later period of prolonged rest, with food-consumption above the normal rate.

Dr. Flint, who paid much attention to this subject, concluded, as the result of the study of the working of the muscular system of a celebrated pedestrian (Weston), about 1870, during a walk of 318 miles in five days, weighing all foods and excretions and noting their composition, that it is as yet impracticable to intelligently compare the force-value of foods with the work of the muscular system; that such estimates, as now customarily made, account only for a part of the work, even leaving out of consideration the energy of other (vital and nervous) actions; that exercise always results in waste of muscular tissues, which may not be repaired at the time; and he also believes that the source of energy is the wasted tissue, and, indirectly only, the nitrogenized food which supplies the waste.

Dalton takes the production of heat in the body at rest, per hour, as about 1.28 British heat-units per pound of its weight. Houghton estimates the work done in walking at one twentieth of the weight of the body in pounds multiplied by the number of feet walked per hour; and it would seem possible, from Flint's computations, that about ten per cent of the total energy-expenditure takes place in the brain and nervous system in the case of man, although that author does not so take it.* The processes involved in the operation

* Source of Muscular Power, pp. 100–103.

of the animal mechanism, to say nothing of its mental part, are too complicated and obscure to permit at present any very accurate statement of their nature, methods, or results.

16. **The Efficiency of the Animal System,** considered as a heat-engine—a probably incorrect assumption—is very high as compared with the machines of that class constructed by man. Helmholtz concluded from the experiments of Hirn that the thermodynamic efficiency of the system is about 0.20, confirming Hirn's own earlier deduction that it is more efficient than the steam-engine as ordinarily constructed. The fact, however, that the body is sensibly uniform in temperature throughout, and that the more work done the more rapid the circulation, and the more certain this uniformity of temperature, seem to prove it impossible that such thermodynamic processes are carried on in the animal system as are familiar to us in our heat-engines, in which the maximum possible efficiency is proportional to Carnot's function—range of temperature divided by maximum absolute temperature. Whatever its method of operation, therefore, the animal machine evades Carnot's law, and must illustrate some as yet undiscovered process of energy-transformation.

17. **The Work of the Animal Machine** is measured in "horse-power"—a rate equivalent to 550 foot-pounds per second, 33,000 per minute, 1,980,000 per hour; 75 kilogrammeters per second, 4500 per minute, 270,000 per hour, in British and metric measure respectively; the latter, however, being, as will be seen by comparison, one seventieth less than the former. Its measure may also be taken as a *day's work*, which may have widely different dynamic values in different cases.

The horse, if of average weight and condition, should do a day's work at the rate of about two thirds of a horse-power unit, or 22,000 to 25,000 foot-pounds per minute for the day. A powerful horse may give a full horse-power, and any animal may do for a short time vastly more than its average rate of work. A man rated at from a sixth to a tenth horse-power can, for a minute or two at a time, perform a full horse-power, or even more.

The daily work of the animal, at its best, depends upon its exact accommodation to most favorable conditions for the development of the best work of the individual, and upon its size, natural strength, endurance, and spirit. These qualities in turn are dependent upon the breed, the state of health, and the general condition of the animal, its food, its environment, the weather, the climate, and the adaptation of its load to its habits and training. While at work the main elements of most effective operation are the load and the speed adopted, at the time, and its distribution, day by day and hour by hour. At maximum load the animal does minimum work; at maximum speed it can carry no load; at some intermediate load and speed it gives maximum work, and this maximum varies with the time of working, day by day. It is higher for short, lower for long, working-days. For continuous work it is usually assumed that eight hours a day, at one third maximum speed and under one third maximum load, gives highest results; but this is true only under most favorable conditions, with animals capable of doing a full day's work, day by day, continuously without loss of strength. In many cases four hours, and sometimes even one, constitute a fair day's work.

Animal power is most remarkably developed in the birds of fast or of long flight. A man can exert 0.25 horse-power for a few minutes at a time, 0.15 horse-power by the hour—which, at 150 pounds weight of the man, would require 600 to about 700 pounds per horse-power. The horse weighs 1500 or 2000 pounds per horse-power; but the birds develop power at the rate of probably less than one third those figures for the former, and one eighth or one tenth for the latter. Falcons fly 60 miles an hour, pigeons 35 to 60 for hours together, and the albatross accompanies fast steamers thousands of miles without halt or rest. The birds weighing probably 100 to 200 pounds per horse-power can carry for a time an added load of 30 to 50 per cent, as when the carnivorous birds carry away their prey.

According to M. Fourier, the daily work of a good horse has a maximum, under the best load for each speed, at about 0.90 (2.95 feet) meters per second, or 3200 (10.596 feet, 2 miles, nearly), an hour. Taking this maximum as unity, he gives the following as probable values of work per pound at other speeds:*

SPEED PER HOUR.		DAILY WORK.
Metres.	*Miles.*	
2,000	1.25	0.69
3,200	2.00	1.00
4,000	2.50	.99
6,000	3.75	.94
8,000	5.00	.83
10,000	6.25	.68
12,000	7.50	.51
14,000	8.75	.33
16,000	10.00	.18
18,000	11.25	.07

* Génie rural, Hervé Mangon; t. III., p. 175.

Where the animal must develop maximum power continuously at any considerable speed, the number required for a specific work will always be greatly increased. Thus, in coaching, the proprietors of mail-coaches, even on the admirable highways of Great Britain, maintain one horse per mile of route for each coach and worked in fours, so that, going and returning, each travels 8 miles per day, working only an hour or less each day on the average. The coach weighs, loaded, two tons, and its coefficient of friction on good roads is about 0.035. Draught-horses at 2.5 miles an hour are expected to do seven times the work of coach-horses at 10 miles.*

18. Tabulated Figures for the work of men and animals follow, as given by Coulomb, Navier, Poncelet, Rankine,† and others. Tables A, B, C, D, etc.

According to Mr. Box, the work of men and animals may be taken, in foot-pounds per minute, as:

		Hours per Day.			
	V	4	6	8	10
Man at a winch.......	220	3,730	3,030	2,640	2,370
" " " treadmill....	130	5,510	4,490	3,890	3,460
" " " capstan.....	118	4,420	3,590	3,100	2,770
Horse at a capstan....	176	24,780	20,260	17,520	15,670
Mule " " "	180	16,530	13,460	11,680	10,390
Ox " " "	120	22,044	17,980	15,570	13,920
Ass " " "	157	6,060	5,610	4,850	4,320

The average effort of a man at a winch should not be assumed above 15 pounds for a day's work, although more than double that figure may be easily attained for a brief period. From 20 to 30 turns a minute is a

* Barbour's Cyclopædia of Manufactures.

† Steam Engine, Chaps. II., III.

A. WORK OF A MAN.—RANKINE.

Kind of Exertion.	R lbs.	V ft. per sec. and per min.	$\frac{T''}{3600}$ (hours p. day).	RV ft.-lbs. per sec. and per min.	RVT ft.-lbs. per day.
1. Raising his own weight up stair or ladder...n..........	143	0.5 30.0	8	72.5 455.0	2,088,000
2. Hauling up weights with rope, and lowering the rope unloaded....n.............	40	0.75 45.00	6	30 1800	648,000
3. Lifting weights by hand. ...	44	0.55 33.00	6	24.2 1452.0	522,720
4. Carrying weights upstairs and returning unloaded....	143	0.13 7.80	6	18.5 1110.0	400,000
5. Shovelling up earth to a height of 5 ft. 3 in..n... ...	6	1.3 78.0	10	7.8 468.0	280,800
6. Wheeling earth in barrow up slope of 1 in 12, ½ horiz. veloc. 0.9 ft. per sec., and returning unloaded........	132*	0.075 4.50	10	9.9 594.0	356,400
7. Pushing or pulling horizontally (capstan or oar).......	26.5	2.0 120.0	8	53 318.0	1,526,400
8. Turning a crank or winch....	12.5 18.0 20.0	5.0 & 300 2.5 & 150 14.4 & 864.0	? 8 2 mins.	62.5; 3750 45; 2700 288; 17280	... . 1,296,000 ....
9. Working pump.......n.......	13.2	2.5 & 150.0	10	33; 1980	1,188,000
10. Hammering.....	15	?	8?	?	480,000

* Net weight of earth in the barrow.

B. PERFORMANCE OF A MAN IN TRANSPORTING LOADS.

Kind of Exertion.	L lbs.	V ft. per min. and per sec.	$\frac{T}{3600}$ (hours p. day.)	LV lbs. conveyed 1 foot.	LVT lbs. conveyed 1 foot.
11. Walking unloaded, transport of own weight............	140	300 5	10	700	25,200,000
12. Wheeling load L in 2-whld. barrow, return'g unloaded.	224	100 $1\frac{2}{3}$	10	373	13,428,000
13. Ditto in 1-wh. barrow, ditto..	132		10	220	7,920,000
14. Travelling with burden......	90	$2\frac{1}{2}$ 150	7	225	5,670,000
15. Carrying burden, returning unloaded..................	140	100 $1\frac{2}{3}$	6	233	5,032,800
16. Carrying burden, for 30 seconds only.....n...........	252 126 0	0 & 702.0 11.7 23.1 & 1386.0	....	0 1474.2 0	....

common range of speed, the handle being 15 to 18 inches long, and about 3500 foot-pounds per minute a fair performance.

Mr. D. K. Clark gives the following as the work, for one day, of a laborer, under the specified conditionsa

Load.		
Kind.	Weight.	Work.
Carrying brick...	106 lbs.	600 mile-lbs.
" coal....	100 "	342 " "
Loading wagon..	100 "	270 " "
" boat....	190 "	1230 " "

One man breaks 1.5 cubic yards of stone, or quarries 5 to 8 tons of rock per day.

The walking speed of man is three to four miles an hour. Running eight miles an hour is a common limit; but 100 miles in a day for a week together, and 11½ miles in one hour, have been attained by practised pedestrians. "aOne hundred yards dashă" has been accomplished at the rate of 20 miles an hour. A skater has attained in one mile over 20 miles an houra on the bicycle about 30 miles an hour has been reached; 50 miles has been made in 2½ hours, 100 miles in 6 hours, 388 in 8 hours, 900 in 72.4 hours.* Swimming long distances only an average of about one mile an hour has been made by man; but the porpoise plays about the bow of ocean steamers making 14 and 15 miles (statute) or more per hour.

Ruhlmann finds the work done by a Prussian soldier on the march, carrying 64 pounds, to be about 3,000,000 foot-pounds per day. Various authorities give about

* Whittaker's Almanach, 1893.

2,000,000 foot-pounds when ascending mountains, and from 1,250,000 to 2,500,000 turning a winch.

It is customarily assumed that a horse may develop 22,500 foot-pounds per minute throughout a day's work of eight hours; will carry 250 pounds 25 miles in a day of eight hours, and that 1500 pounds, wagon included, is a good load for a horse drawing it on good roads 25 miles a day of eight hours. The regular load rarely exceeds one half the maximum. The load which can be raised by a bird is said to be about one half its own weight as a maximum.

Weisbach states that a man can walk, unloaded, ten hours a day at 3½ miles an hour; carrying 80 pounds, he can walk seven hours at two thirds that speed. He can walk upstairs, unburdened, at the rate of 0.48 foot per second, eight hours a day, and performing 1,935,360 foot-pounds of work per day, assuming his weight to be 140 pounds. He can traverse, without load, 12.5 times as much space horizontally as vertically. A day's work with a "rammer," such as is used by paviors, is given as 1,142,400 ft.-lbs. Turning a crank, man accomplishes 1,175,040, with a mean effort of 16 pounds and a speed of 2.4 feet per second during a working day of eight hours. On a capstan an able-bodied man, also, can perform 1,382,400 foot-pounds of work per day. On the treadmill he attains 1,750,000 foot-pounds.

The estimates of General Jouffret yield the following*: "According to the *Guide Joanne*, the ascent of Mont Blanc, starting from Chamounix, is effected in seventeen hours, resting-spells not included. The difference of level is 3760 metres. A person ascending

* Théorie de l'Énergie; Paris, 1885.

who has a mean weight of 70 kilogrammes produces, then, in order to rise, a work of $3760 \times 70 = 263,000$ kilogrammetres. This work is borrowed from the heat that the carbon and hydrogon contained in the food eaten disengage upon being burned in the lungs. For the sake of simplicity, if we reduce the entire energy to a combustion of carbon, and recall that a kilogramme of the latter furnishes 3,000,000 kilogrammetres, we find that the 263,000 kilogrammetres represented by the ascent correspond to a consumption of 94 grammes of coal—a consumption that should be added to the normal rations necessary for the operation of the organs during a state of rest. Such consumption is 8.35 grammes per hour, or 142 grammes for the seventeen hours. The total consumption of coal is 256 grammes, representing 708,000 kilogrammetres. The performance, then, is

$$\frac{263,000}{708,000} = 37 \text{ per cent.}$$

"The performance of the human machine drops to 21 per cent when we consider a period of twenty-four hours composed of ten hours of work and fourteen of rest, and a mean daily work of 280,000 kilogrammetres.

"The cannon, considered as a machine, is incomparably superior to a steam-engine as regards the time necessary to produce a given quantity of mechanical work.

"Thus, for example, the 100-ton cannon develops in *one hundredth of a second* a quantity of work equal to that which would be yielded by a 47-horse-power steam-engine *in one hour*. A man of average strength is still lighter than an ordinary steam engine of equal power, but he is much inferior to the other animals of creation, and particularly to insects.

C. WORK OF A HORSE AGAINST A KNOWN RESISTANCE.

Kind of Exertion.	R	V	$\frac{T}{3600}$	RV	RVT
1. Cantering and trotting, drawing a light railway carriage (thoroughbred)	min. 22½, mean 30½, max. 50	14⅔	4	447½	6,444,000
2. Horse drawing cart or boat, walking (draught-horse)	120	3.6	8	432	12,441,600
3. Horse drawing a gin or mill, walking	100	3.0	8	300	8,640,000
4. Ditto, trotting..........	66	6.5	4½	429	6,950,000

D. PERFORMANCE OF A HORSE IN TRANSPORTING LOADS HORIZONTALLY.

Kind of Exertion.	L	V	$\frac{T}{3600}$	LV	LVT
5. Walking with cart, always loaded	1,500	3.6	10½	5,400	194,400,000
6. Trotting ditto..................	750	7.2	4½	5,400	87,480,000
7. Walking with cart, going loaded, returning empty; $V = ½$ mean velocity	1,500	2.0	10	3,000	108,000,000
8. Carrying burden, walking.......	270	3.6	10	972	34,992,000
9. Ditto, trotting............	180	7.2	7	1,296	32,659,200

The average weight of a horse or an ox may be taken as thuse

Light carriage-horse . . e. . . e. e.	800 lbs.
Heavy "	1200 "
Light draught-horse. . . . e. e. .	1000 "
Heavy " ....e. e.	1600 "
Ox.........................	1000 "

The horse has galloped a mile in 1 minute 43 seconds, or at the rate of 35 miles an hour, and trotted a mile in 2 minutes 4 seconds, or 29 miles an hour.

An Austrian army officer rode, in June, 1893, from Vienna to Berlin, 388 miles, in 71.33 hours, or 5.45 miles an hour, resting an hour in twelve, but losing his horse after the race was concluded. The "cyclistsë" have beaten this record.

Rennie found the hauling power of a draught-horse weighing 1200 pounds was equal to about 108 pounds at 2.5 miles an hour, or 22,300 foot-pounds per minute, for eight hours per day, a 20-mile haul. This is a little over two thirds of a Watt "horse-power," at which value Rennie rates the average draught-horse, and this is taken to be, ordinarily, five times the power of a man. Between 2½ and 4 miles an hour, the hauling power of the horse is nearly inversely as the speed.

The mule carries a load of 200 to 400 pounds, and its day's work consists, usually, in the transportation of the equivalent of 5000 to 6000 pounds one mile. The ass carries 175 pounds and upward, and the day's work is the equivalent of 3000 to 4000 pounds one mile.

According to Weisbach, a horse should be able to carry 240 pounds on its back 3.5 feet per second ten hours a day. Carrying 160 pounds he should be able to trot 7 feet per second seven hours a day, doing, in the day, ten per cent less work than before, nearly.

The pulling power is said to be, as a rule, about one fifth the weight of the animal. Its usual effort, in the case of the horse at least, is seldom in excess of one tenth, or about one half the maximum. One hundred pounds is a common pull for the average horse in draught vehicles.

19. Effective Methods of Application of man-power are sought by the engineer. The best is considered to be that of Coignet; who arranged hoists in such manner that the men employed would go up ladders or stairs to the summit of the lift and then, by their weight applied to the "fall" of the tackle used, descending to the ground thus suspended, the work of their descent would be transmitted to the hoist and raise the load. Tables B, C, D, are for common roads. Rankine gives as the approximate relative power of various animals the following: The ox draws a load about equal to that of the horse, the mule one half, the ass one fourth. The ox moves at two thirds the speed of the horse, the mule the same velocity as the horse, the ass the same; making their respective working powers as 1 to $\frac{2}{3}$, to $\frac{1}{2}$ and $\frac{1}{4}$, respectively. In all cases, the practical limit is determined by the method of application, the character of the vehicle, if any, used, and the adjustment of the animal to its surroundings, as well as by its own physical characteristics. Animals do their work mainly by draught of vehicles. Its amount depends largely upon the character of the road traversed. The effort required may be taken as approximately as follows, for total loads, including the vehicle:

Good country road.........	50 lbs. per ton.
Macadamized surfaces.....	40 " " "
Asphalt pavements........	38 " " "
Wood "	35 " " "
Granite tramways........	27 " " "

Granite pavement, dry, is less likely to cause falls than either wood or asphalt; when wet, wood is best in this respect. Macadamized and earth roads are safer than either of the pavements.

20. The Draught of Vehicles is a case of rolling friction.* Morin, who made very extended experiments, states its laws as follows:

(1) On hard surfaces, as paved and macadamized roads, the resistance is directly proportional to the weight of vehicle and load, inversely proportional to the diameter of wheel, and independent of the breadth of wheel-tire. It increases with velocity.

(2) On soft ground the resistance increases inversely as the breadth of tire. It does not sensibly vary with velocity. Morin concludes, also, that the line of draught should be horizontal.

Dupuit, on macadamized roads, found the resistance to vary nearly inversely as the square root of the diameter of wheel and directly as the load. He found the resistance on pavements to be increased at high speeds by the concussions incident to rapid movement. Clark obtains a somewhat less simple law, which he expresses thus:

$$R = a + bv + \sqrt{cv}. \quad . \quad . \quad . \quad . \quad (1)$$

The work of hauling is then

$$U = Rs = (a + bv + \sqrt{cv})vt. \quad . \quad . \quad . \quad (2)$$

This formula is deduced from the experiments of Macneil on "metalled" roads.† The values of the constants are, in British measures, $a = 30$; $b = 4$; $c = 10$ pounds per ton, v being given in miles per hour, t in hours.‡

* Friction and Lost work; Thurston, p. 84.

† Clark's Manual, p. 964.

‡ Parnell on Roads, p. 464.

The resistance of all vehicles on common roads and streets is principally resistance to rolling, their axle-friction being comparatively small. The work of hauling is, then,

$$U = Fs = fWs = fWvt. \quad . \quad . \quad . \quad . \quad (3)$$

The draught of vehicles loaded in any stated manner may be made comparatively easy or difficult by proper or improper methods of attachment of the animal to the vehicle.*

The general principles to be observed are the following:

(1) In hauled loaded vehicles, the line of traction should be made such as to make the hauling power dependent upon adhesion between the animal and the ground equal to the resistance of the vehicle, with some margin of insurance against occasional slipping.

(2) The heavier the load, if in excess of the hauling power due the animal's weight, the more should that weight be reinforced by so adjusting the line of traction that it may have a vertical component tending to raise the load and increase the holding and hauling power of the feet of the animal.

(3) With loads lighter than those demanding the total adhesion due the weight of the animal, the line of traction should be so located that the haul, and, if possible, the load itself, may take off a part of the animal's weight.

Thus, with a two-wheeled vehicle the load may usually be so distributed as either to be carried, in part,

* Mr. T. H. Brigg has made a study of this point, with interesting results. Trans. Am. Soc. M. E., 1893.

by the horse, or to balance a part of the weight of the animal; the latter either carrying part and hauling part of the load, or hauling the load and, with it, a part of its own weight, transferred, by the inclined upward line of traction, to the load. The former disposition is obviously suitable for heavy loads and steep gradients, the latter for light loads and level or falling stretches of road. Heavy wagons should be handled in such manner as to give the former, light carriages the latter, adjustment. It would probably, in the case of the heavy vehicle be well to provide, if practicable, for the change of the line of pull to suit the load and gradient, as has been practised by Mr. Brigge who finds, in some cases, a loss of one half the mechanical efficiency attainable, due to inappropriate methods of attachment of the animal to the vehicle.* He concludese

"The resistance which a horse can overcome depends upon the following conditions: (1) his own weight; (2) his grip; (3) his height and length; (4) direction of trace; (5) his muscular development, which determines the power to straighten the bent lever represented by his body and hind legs against the two resistances, the vehicle through the trace attached to the shoulder and the hind feet against the ground.

"To pull through a very low trace, or to have a man, or even two or three men, on a horse's back is advisable and even necessary if a horse is expected to haul a load requiring the full force of his muscles at any particular moment—and for the moment, under such conditions, he would be able to draw a much greater load than without the added weight. But any person can

---

* Ibid.

see that the animal could not travel far with any vehicle if he must carry three men on his back in addition to hauling his load."

"Therefore, to deal justly with our horses, we should not only study cause and effect, but should devise some means by which, automatically, every possible advantage could be given to the horse at all times.* Otherwise there must be a constant waste of energy, tiring the horse prematurely and increasing the chances of his stumbling and falling."

These principles are thus illustrated by Mr. Brigge

In the accompanying figure, let the horse be harnessed in the usual manner and driven up hill.

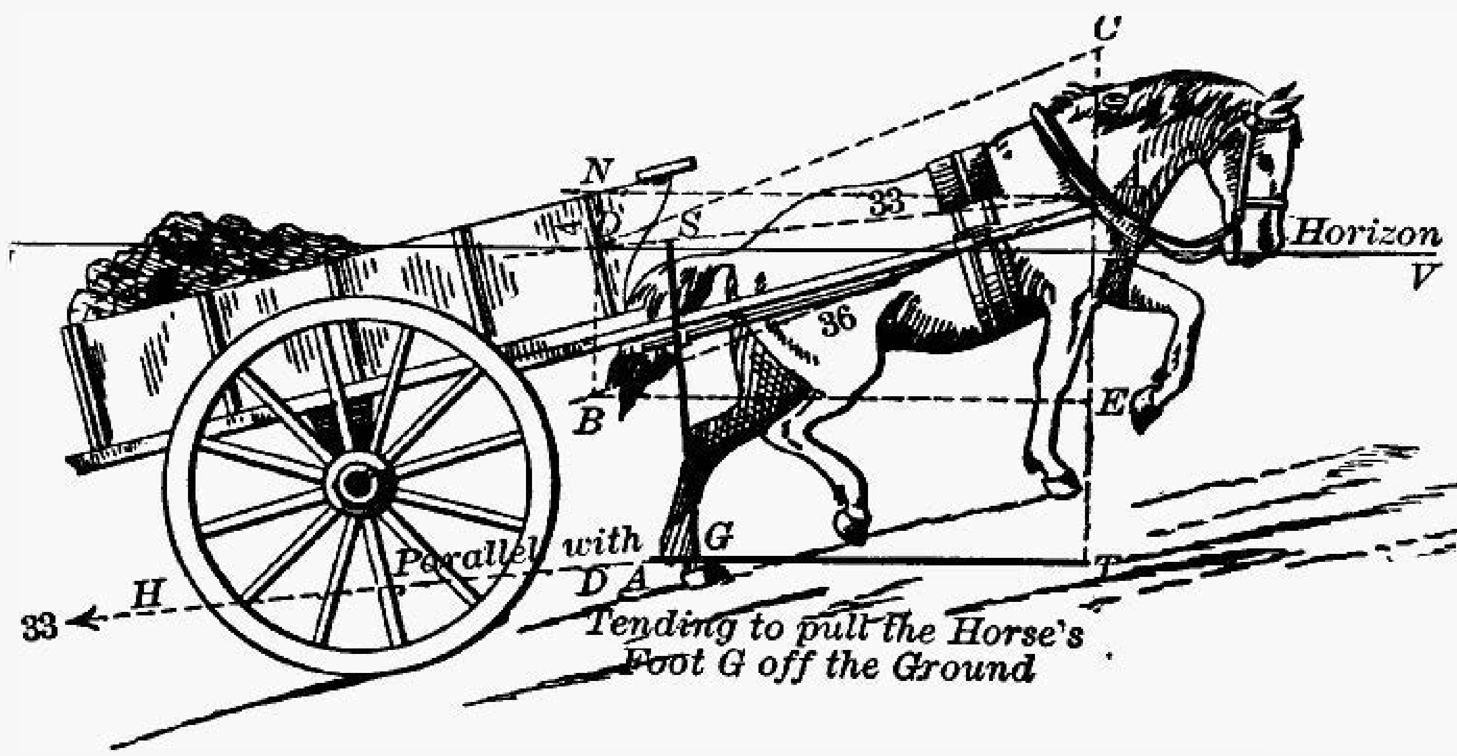
Suppose that the horse is exerting a force of 36 lbs. through *AB* in a line from the hame to the centre of the wheel. Let *AC* represent the vertical depression necessary to hold down the shafts. Since *AB* and *AC* are the forces necessary to produce motion, by completing the parallelogram *ACDB* we find that *AD* represents the resultant of the forces *AC* and *AB*. Thus we determine one arm of the lever, *GS*, acting against *GT*, the other arm. *GS* is a line drawn at right angles from the resolved angle of force *AD*.

If the load had been balanced on the axle, then, regardless of the angle of trace or hame-chain, the angle of draught would be through *AB* to the centre of the wheel. Then a line at right angles with *AB* to *G* would have been the short arm of the lever, which would have enabled the horse to have pulled a much greater load than is possible with the longer arm, *GS*. But,

* Mr. Brigg had already devised and applied such a system of self-adjustment of the harness as to secure this effect.

the load being behind the axle, the forward weight of the animal is reduced by the lift of the shafts at *A*, and the result is the same as if the traces had been put up at the point *D*, and the load, with a 33-lb. pull through such a trace, would be exactly balanced.

Let *UV* represent the horizon passing through the point *D*. If *DA* represents 33 lbs., then *FA* will



Resultant of Components A B and A C as A D, or N D added to Horse's Weight, N D equals 4 taken from the Load and Carried by the Horse.

FIG. I.—HAULAGE OF VEHICLES.

represent 4 lbs., so that 4 lbs. must be added to the horse's natural weight by the pull *AD*. Or, if the pull through the trace *AB* is 36 lbs., then, drawing *BE* parallel with the horizon *UV*, *EA* (14 lbs.) will represent the depression due to a 36-lb. pull through *AB*. But when the lift due to the shafts, 10 lbs., is deducted from the depression of 14 lbs., there remains as before an increased weight of 4 lbs. on the horse.

When the horse is pulling with the same force upon a level, as in Fig. 2, we find very different results. Let *PA* be the direction from the hames to the centre of the wheel and representing a 36-lb. pull. The load having been moved farther to the rear, the lift at the belly-band is still 10 lbs. at *P*—the load is moved backward to shift the centre of gravity. The resultant of the two components *PA* and *PB* is *PC*, and *PC* now equals about 35.9 lbs., whereas the resultant *AD* in Fig. 6 is only 33 lbs., or 2.9 lbs. less than on the level. It will now be found that 36 lbs. pull through *PA* will increase the horse's weight 4.5 lbs., represented by *PO*, which is determined by drawing *AO* from *A* parallel with the horizon, cutting the line of gravity *PE*.

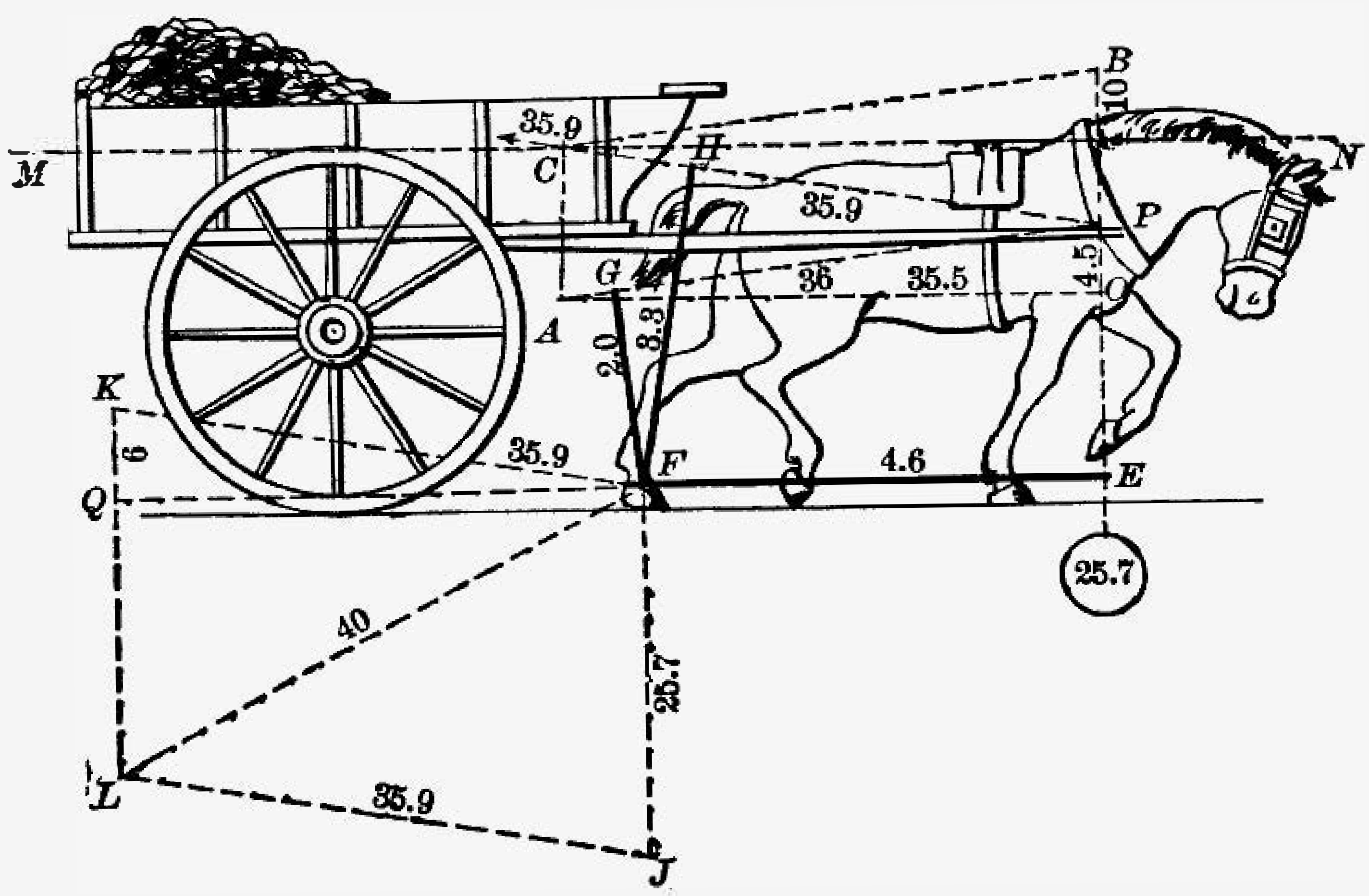


FIG. 2.—HAULAGE OF VEHICLES.

But, as the disposition of the load is such that 10 lbs. are taken from the horse, it is obvious that, if only 4.5 lbs. are put back by the stated pull of 36 lbs., the horse has still 5.5 lbs. less than his natural weight in Fig. 2, while in Fig. 1 he has 4 lbs. more than his natural weight.

If the load be shifted to the front end of the cart, as indicated in Fig. 3, the resultant of the forces *PJ* and *PK* lies in the direction of *PL*, and the added

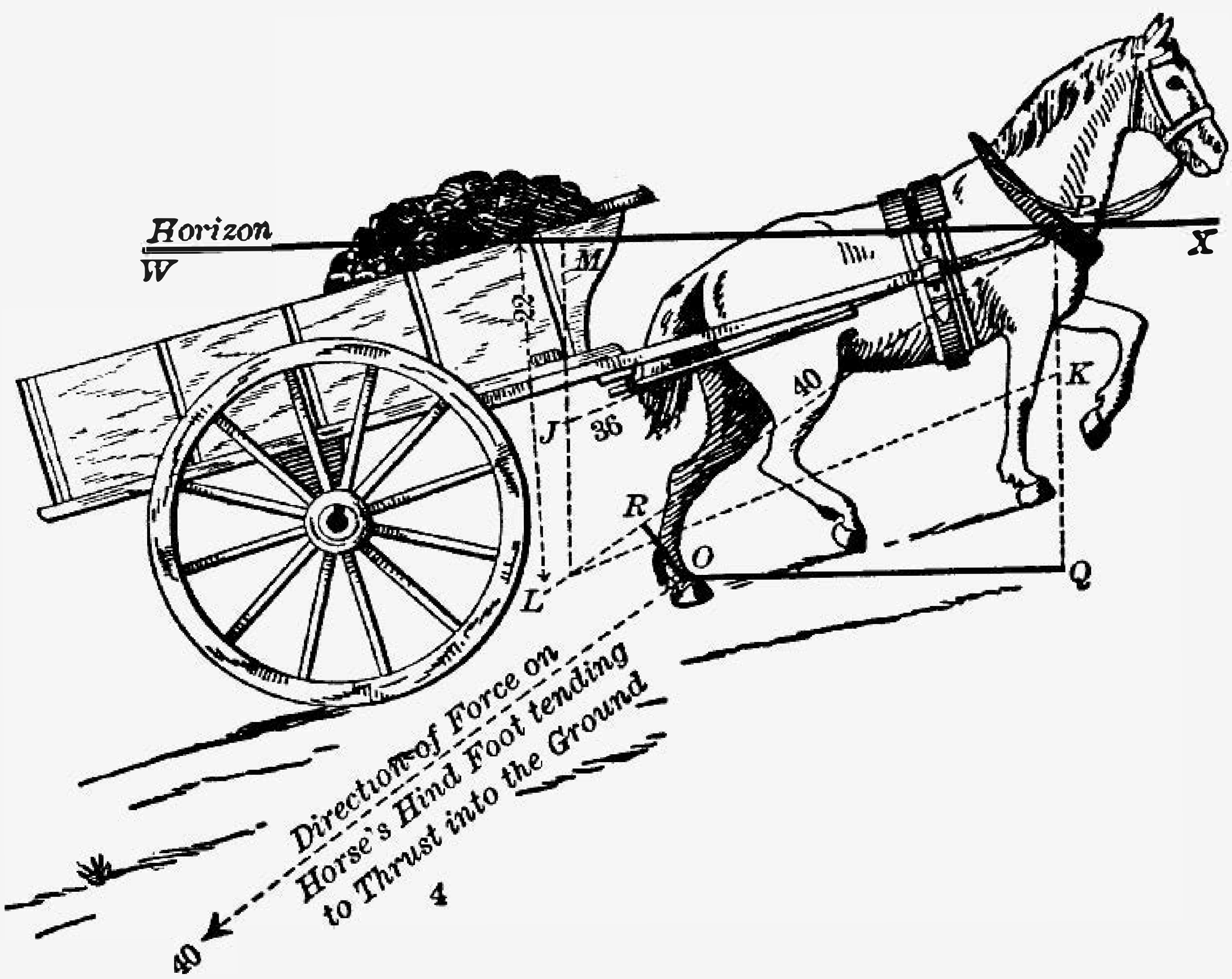


FIG. 3.—HAULAGE OF VEHICLES.

weight on the horse is 22 lbs. instead of 4 lbs. as in Fig. 1, tending to thrust his hind foot into the ground at *O*, and he is able to pull 40 lbs. as against 33 lbs. under the conditions indicated in Fig. 1.

It will be observed in Fig. 1 that the point of application of force *A* (the hame) is above the horizontal line *UV*, drawn through the point *D*, this being the point at which the traces might be fixed with an advantage equal to having them attached to the axle when the given lift is exerted at *A*, with a lift at the belly-band as set forth; whereas *P*, the point of application of force in Fig. 2, is now much below the horizontal line *MN*, drawn through the point *C* on the resultant, or virtual line of draught. Comparing the triangles *ABE* (Fig. 1) and *PAO* (Fig. 2), *AB* and *PA* represent the pull through the traces, and, although the force is the same—36 lbs., the result is different.

If *AB* in Fig. 1 represents a 36-lb. pull, and *AC* a 10-lb. lift, then *AD* (33 lbs.) is the resultant direction of force applied by the animal. A 36-lb. pull through *AB*, together with a lift of 10 lbs. through *AC* or a pull of 33 lbs. through *AD*, will both be effective in lifting 2.6 lbs. from the horse's fore quarters.*

Thus the animal may be very effectively aided, or may be totally incapacitated by good or bad adjustment of the line of traction. In all cases this line should be given such inclination as will insure increased pressure of the animal upon the ground for heavy pulling, and decrease its weight in the opposite case, just to the extent required to make adhesion ample without unnecessary surplus.

21. Muscular Power varies enormously with the animal, its condition, habits of exercise, and other circumstances; but the results of many experiments indicate that the muscles of the human body have a power measured, in good condition, by a maximum of not far from 10 kilogrammes per square centimetre, and averaging 7 or 8 (142,110,114 pounds per square inch respectively). The influence of exercise and custom on the working power of the muscle is enormous, in some cases being found to vary in the proportion of

---

* Ibid.

one to at least three.* This quantity of work done has no ascertained relation to the value of the energy of the foods consumed; although the work which an animal can do is dependent upon the quantity of energy-producing food which it can digest and assimilate under the conditions to which it is subjected while at work. The stored energy of the foods varies, according to Frankland, from about 500 kilogrammes per gramme, or 45 foot-pounds per ounce, for lean meats, to three times this quantity for the grain-foods and to six times this value for butter; but the total need of the system determines the kind and quality of food desirable at any given time and for any given case. In general the use of the grain-foods is, from a scientific and possibly from a physiological point of view, most productive of useful power in both man and the domestic animals. Where the work is severe and long-continued no time is allowed for proper digestion and assimilation, and in such cases special care must be taken to provide the best conditions for insuring endurance. It is in illustration of this point that the case of the Arab living on the coffee-berry, and the pedestrian on long walks living entirely on the same material in the form of a beverage, may be referred to. The warm drink is at once stimulus and food, and demands little energy in digestion and assimilation. A permanent dietary, however, must contain all the elements demanded for nutrition of all parts of the system in proper proportions, and must at the same time provide the needed mechanical and other stimuli of all the organs of the body. The *whole* wheat used by man, fruits, and the

* Nipher on Strength of the Muscle, *Am. Jour. Sci.*, Nov. 1875.

grains consumed by horses and cattle are considered to be most perfect examples of these foods. Eggs and milk, among animal foods, correspond most nearly to the same desirable composition, but require an admixture of vegetable foods to insure their proper action in the human system. The meats are always defective in essential elements of food, and can never be safely used alone by man. The carnivora, devouring the whole body of their prey, and especially fond of the blood, which contains all its elements in solution, are able thus to live upon animal food.

Working animals are always herbivorous or graminivorous, and, as in the case of man, should have their best dietary carefully determined to insure their efficient action as prime movers, and maximum economy of transformation of the potential energy of their foods into mechanical power. When doing no work an herbivorous diet is probably beste but when working the grains, and when hard worked "cut feed" and coarse meals, mixed with a moderate amount of water and given warm, are best. Cold water should be avoided with meals, and when the creature is warm from exertion especiallye but oat-meal water can be safely taken in any quantity by man or beast.

22. **The Uses of Foods** in the body are thus stated by Professor Atwater*:

Food furnishes:

(1) The material of which the body is made.

(2) The material to repair the wastes of the body, and to protect its tissues from being unduly consumed.

Food is consumed as fuel in the body to:

(3) Produce heat to keep it warm.

---

* *Century Magazine*, July 1887, p. 370.

(4) Produce muscular and intellectual energy for the work it has to do.

The body is built up and its wastes are repaired by the nutrients. The nutrients also serve as fuel to warm the body and supply it with strength.

The protein of food	*forms* the nitrogenous basis of blood, muscle, sinew, bone, skin, etc. *is* changed into fats and carbohydrates. *is* consumed for fuel.
The fats of food	*are* stored in the body as fat. *are* consumed for fuel.
The carbohydrates of food	*are* changed into fat. *are* consumed for fuel.
The mineral matters of food	*are* transformed into the mineral matters of bone and other tissue. *are* used in various other ways.

A growing child or young animal requires much muscle and nerve-making material, and the proportions of the several elements in the food are more nearly those of the body itself than in the case of the adult. The adult, when doing little work, requires little food, and that mainly of the kinds which are required to supply heat and to compensate the slight wastes of tissue then occurring; while the working system, and particularly if hard worked, demands considerable quantities of combustible, heat-producing food. Similar differences of dietary are required, as the climate compels the development of more or less of caloric to preserve the temperature of the body, which at above 104° Fahr., or a little below 98°, fails to meet the requirements of life.

According to Dr. Letheby, the working-power of the human body may be taken as follows*:

---

* Letheby on Food, p. 96.

	Foot-pounds.
External work or actual labor..e	1,011,670
Work of circulation (75 beats a minute).e..	500,040
Work of respiration (15 a minute)......e...	98,496
Total ascertainable work per day......	1,610,206

The ascertainable external and internal work of the food we eat is only one sixth of its actual energy, according to Lethebye; but it is not impossible that the unascertained work of the vascular system and other parts may account for the full amount, nearly.

According to Dr. Frankland, this power is supplied by food in the following proportionse*:

ENERGY-VALUES OF FOODS.

Name of Food.	Per Cent of Water in Material.	Pounds of Water Raised 1° F.		Pounds Lifted 1 Foot High.	
		When Burnt in Oxygen.	When Oxidized in the Body.	When Burnt in Oxygen.	When Oxidized in the Body.
Butter..............	15	18.68	18.68	14.421	14.421
Cheese.............	24	11.95	11.20	9.225	8.649
Oatmeal....	15	10.30	10.10	7.952	7.800
Wheat flour........	15	10.12	9.87	7.813	7.623
Peameal............	15	10 12	9.57	7.813	7.487
Ground rice	13	9.80	9.52	7.566	7.454
Yolk of egg.........	47	8.82	8.50	6.809	6.559
Lump sugar.........	19	8.61	8.61	6.649	6.649
Entire egg (boiled)..	62	6.13	5.86	4.732	4.526
Bread...............	44	5.74	5.52	4.431	4.263
Ham...............	54	5.09	4.30	3.929	3.321
Mackerel	71	4.60	4.14	3.551	3.200
Lean beef..........	71	3.38	3.01	2.609	2.324
Lean veal..........	71	3.38	3.01	2.609	2.324
Potatoes...........	73	2.60	2.56	2.007	1.987
Milk............. .	87	1.70	1.64	1.312	1.246
Carrots............	86	1.36	1.33	1.050	1.031
Cabbage...........	89	1.12	1.08	.864	.834

* Frankland on Food of Man, 1887, p. 68.

23. Dietaries.—Dr. Pavy gives the following as the quantities of the specified foods required to support human life*:

Nitrogen	300 grains.	
Carbon	4800 "	

	Carbon.	Nitrogen.
14,000 grains (2 lbs.) of bread contain	4200	140
5,500 " (about ¾ lb.) of meat contain	605	165
Total (2¾ lbs.)	4805	305

Six pounds meat	4800 grains carbon. 1309 " nitrogen.
Four pounds bread	9000 grains carbon. 300 " nitrogen.

The estimates of Moleschott for weight of foods in a dry state, for the average individual, are as follow:†

Dry Food.	In Oz. Avoir.	In Grains.	In Grammes.
Albuminous matter	4.587	2006	130
Fatty matter	2.964	1296	84
Carbohydrates	14.250	6234	404
Salts	1.058	462	30
Total	22.859	9998	648

Reckoning ordinary food to contain 50% of water, then, these 23 ounces will correspond to 46 ounces solid food in the condition eaten —additional to this, 60 to 80 ounces of water is taken in some form. The dynamic or force-producing value of this daily standard diet amounts to about 4000 foot-tons.

The relative values of the common articles of diet are given by Scammell as follows‡:

* Treatise on Food, p. 473.

† Ibid., p. 452. Also Mott's Chart (N. Y., J. Wiley & Sons, 1889).

‡ Mott's Chemist's Manual, p. 575.

THE RELATIVE VALUES OF FOODS.

Articles.	As Material for the Muscles.	As Heat-givers.	As Food for the Brain and Nervous System.	Water.	Waste.
Wheat	14.6	66.4	1.6	14.0	3.4
Barley	12.8	52.1	4.2	14.0	16.9
Oats	17.0	50.8	3.0	13.6	16.9
Northern corn	12.3	67.5	1.1	14.0	5.1
Southern "	34.6	39.2	4.1	14.0	8.1
Buckwheat	8.6	53.0	1.8	14.2	22.4
Rye	6.5	75.2	0.5	13.5	4.3
Beans	24.0	40.0	3.5	14.8	17.7
Peas	23.4	41.0	2.5	14.1	19.0
Rice	5.1	82.0	0.5	9.0	3.4
Potatoes	1.4	15.8	0.9	74.8	7.1
Parsnips	2.1	14.5	1.0	79.4	3.0
Turnips	1.2	4.0	0.5	90.4	3.9
Cabbage	1.2	6.2	0.8	91.3	0.5
Milk	5.0	8.0	1.0	86.0	....
Veal	17.7	14.3	2.3	65.7	....
Beef	19.0	14.0	2.0	65.0	....
Lamb	19.6	14.3	2.2	63.9	...
Mutton	21.0	14.0	2.0	63.0	....
Pork	17.5	16.0	2.2	64.3	....
Chicken	21.6	1.9	2.8	73.7	....
Codfish	16.5	1.0	2.5	80.0	....
Trout	16.9	0.8	4.3	78.0	....
Salmon	20.0	Some fat	6 or 7	74.0	....
Oysters	12.6	....	0.2	87.2	....
Eggs (white of)	13.0	....	2.8	84.2	....
" (yolk of)	16.9	29.8	2.0	51.3	....
Butter	....	100.0	....	....	....
Bacon	8.4	62.5	0.5	28.6	....
Cheese	30.8	28.0	4.7	36.5	....
Chocolate	8.8	88.0	1.8	....	1.4
Cream	3.5	4.5	....	92.0	....
Ham	35.0	32.0	4.4	28.6	....
Lard	....	100.0	....	....	....
Onions	0.5	5.2	0.5	93.8	....
Barley	4.7	78.0	0.2	9.5	7.6

The study of these figures permits the construction of a proper dietary for any case in which stated rations are required or desirable. Professor Atwater gives the following*a

* *Century Magazine*, 1858, p. 258.

STANDARDS FOR DAILY DIETARIES.*

WEIGHTS OF NUTRIENTS AND CALORIES OF ENERGY (HEAT UNITS) IN NUTRIENTS REQUIRED IN FOOD PER DAY.

	Nutrients.				Potential Energy.
	Protein.	Fats.	Carbohydrates.	Total.	
	Grms.	Grms.	Grms.	Grms.	Calories.
1. Children to 1½ years	28 (20-36)	37 (30-45)	75 (60-90)	140	767
2. Children 2 to 6 years	55 (36-70)	40 (35-48)	200 (100-250)	295	1418
3. Children 6 to 15 years	75 (70-80)	43 (37-50)	325 (250-400)	443	2041
4. Aged woman	80	50	260	390	1859
5. Aged man	100	68	350	518	2477
6. Woman at moderate work (Voit)	92	44	400	536	2426
7. Man at moderate work (Voit)	118	56	500	674	3055
8. Man at hard work (Voit)	145	100	450	695	3370
9. Man with moderate exercise Playfair)	119	51	531	701	3139
10. Active labor (Playfair)	156	71	568	795	3629
11. Hard labor (Playfair)	185	71	568	824	3748
12. Woman with light exercise (Writer)	80	80	300	460	2300
13. Man with light exercise (Writer)	100	100	360	560	2820
14. Man at moderate work (Writer)	125	125	450	700	3520
15. Man at hard work (Writer)	150	150	500	800	4060

DIETARIES FOR MAN DOING MODERATE MUSCULAR WORK.

	Nutrients.			Potential Energy.
	Protein.	Fats.	Carbohydrates.	
Playfair	119 grms.	51 grms.	530 grms.	3135 calories
Moleschott	130 "	40 "	550 "	3160 "
Wolff	120 "	35 "	540 "	3032 "
Voit	118 "	56 "	500 "	3055 "

Mr. Edward Atkinson has given a number of dietaries, each having the requisite proportion of proteids,

* Nos. 1, 3, 4, and 5 are as proposed by Voit and his followers of the Munich School; No. 2 by Atwater. One ounce = 28⅓ grammes, nearly.

starch, and fat for thorough nutrition with minimum consumption of food and at minimum cost. Of these the following is an example of a dietary which would serve where low wages or other conditions compel the adoption of most economical rationsa

LOW-COST DIETARY.*

Article.	Pounds.	Proteid.	Fat.	Carbo-hydrate.	Calories.	Cost at Boston prices 1891.
Flour........	22	2.64	.44	15.18	36,520	$0.55
Grain........	12	1.68	.84	7.60	19,800	.48
Butter.o.....	2	.02	1.73		7,230	.56
Suet..........	2		1.78		7,200	.12
Sugar....o....	2			1.93	3,600	.10
Potatoes......	10	.20		2.10	4,300	.25
Beets, Carrots, Onions, Squash, Cabbage, Parsnips ..	7	.13	.03	.50	1,120	.25
For 30 days.o.	57	4.67	4.82	27.31	79,770	$2.31
For 1 day.....	1.90	.155	.160	.910	2,659	.077

VARIABLES IN TABLE SHOWING METHOD OF ANALYSIS.

Article.	Pounds.	Proteid.	Fat.	Carbo-hydrate.	Calories.	Cost.
Beef, neck or shin.......	12 (includ'g waste)	2.00	.40		5,200	.72
Mutton, neck.	5	.62	.34		2,476	.30
Bacon........	4	.40	2.80		11,840	.48
Beef-liver....	2	.40	.10		1,120	.12
Veal.........	1	.19	.03		460	.08
Salt Pork.....	1	.03	.78		3,160	.08
For 30 days..	25	3.64	4.45		24,256	1.78
Total.o..	82	8.31	9.27	27.31	104,026	$4.09
For 1 day....	2.73	.277	.309	.910	3,467.5	.136

The succeeding dietary is one which is considered an economical and satisfactory scheme for families of

* The prices on which these computations are made were the retail prices in Boston, Mass., U. S. A., in the first six months of the year 1891.

small income. In both cases the first list will sustain life, and the second comprises the usually added but unessential articles. In acting as commissary the engineer should endeavor always to provide the equivalent of the first dietary, and, where practicable, the second.

Articles.						Calories.
22	pounds	Flour,	at	$0.02½	$0.55	
3	"	Oatmeal,	at	.04	.12	
3	"	Cornmeal,	at	.03	.09	
6	"	Hominy,	at	.04½	.27	
2	"	Butter,	at	.28	.56	
2	"	Suet,	at	.06	.12	
10	"	Potatoes,	at	.02½	.25	
3	"	Cabbages,	at	.03	.09	
2	"	Carrots,	at	.02½	.05	
2	"	Onions,	at	.05½	.11	
2	"	Sugar,	at	.05	.10	
57					$2.31	79,770
Variables.						
6	pounds	shin of Beef,	at	$0.06	$0.36	
2	"	round of Beef,	at	.18	.36	
6	"	neck of Mutton,	at	.06	.36	
2	"	Eggs,	at	.18 doz.	.27	
1	"	Cheese,	at	.16	.16	
30	"	Skimmed Milk,	at	.02	.60	
1	"	White Beans,	at	.07	.07	
1	"	Pease,	at	.07	.07	
4	"	Halibut, nape,	at	.05	.20	
2	"	Haddock,	at	.08	.16	
3	"	Salt Cod,	at	.08	.24	
1	"	Oleomargarine,	at	.16	.16	
2	"	Macaroni,	at	.15	.30	
1	"	Oatmeal,	at	.04	.04	
2	"	Cornmeal,	at	.03	.06	
1	"	Rice,	at	.06	.06	
1	"	Hominy,	at	.04	.04	
66					$3.51	41,051
123	pounds, total for 30 days,				$5.82	120,821
4.1	" " "	1 day,			.194	4,027

Cost per week, $1.35.

24. The "Mechanism of Transmission" of the power of the animal is the vehicle or other apparatus through which the power is exerted in the moving of the load. In some cases the load is directly applied, as where pack-animals are employed; in others a wagon is used; in still other cases the pull on a rope is made effective in raising weights. A strong man can walk an average of about 3½ miles an hour 10 hours a day, unloaded; under 80 pounds he can walk at half this speed seven or eight hours a day; and he may lift at long intervals 180 to 200 pounds. The work of horizontal transport may be approximately computed by taking it at 0.08 the product of weight carried into distance moved over. Thus measured, we find from the above statement that a man should do about 2,000,000 foot-pounds of work per day, his weight being included in the amount taken as load. By the use of a wagon, or its equivalent, the weights that may be transported are increased, often, ten times or more. Training may double the efficiency of a workman in manual employments and enormously increase it in cases of skill coming of long practice. The differences between reputably first-class workmen may amount to 15 or 20 per cent.

The pull of the average draught-animal is usually not far from one fifth its weight. Gerstner gives us the following*:

	Weight. Lbs.	Av. Pull. Lbs.	V ft. per Sec. Av.	Work per Sec.	Work per 8-hr. Day.
Man....	150	30	2.5	75	2,160,000
Horse...	600	120	4.0	480	13,824,000
Ox.....	600	120	2.5	300	8,640,000
Mule....	500	100	3.5	350	10,080,000
Ass....	360	72	2.5	180	5,184,000

* Mechanik, vol. i.

25. **Equations** connecting the time, effort, and work of animals have been proposed, all of which are only approximate, at best; since the conditions of each case are certain to differ more or less from the mean, and are always difficult to evaluate. Rankine follows Maschek, who gives the expression

$$\frac{R}{R_1} + \frac{V}{V_1} + \frac{T}{T_1} = 3;$$

in which R_1, V_1, T_1, are respectively one third, each, of the maximum load, maximum speed, and maximum time in the day's work. Thus a maximum day's work is obtained under the load $R = R_1$, at the speed $V = V_1$, and $T = T_1$, working eight hours per day. Any departure from this adjustment is presumed to give sensible loss of result. Bouguer proposes and Gerstner endorses the following, R_1 and V_1 being maximum loads and speeds:

$$R = \left(1 - \frac{V}{V_1}\right)R_1.$$

Gerstner, taking R_1 and V_1 at their mean values, as per table, would write the equations thus:

$$R = \left(2 - \frac{V}{V_1}\right)R_1; \qquad V = \left(2 - \frac{R}{R_1}\right)V_1.$$

For small variations from the times, loads, and speeds of best effect, the total effect may be taken as varying with those variations.

In ascending inclines, the work may be taken as approximately increasing with the inclination and at a rate proportional to the ratio $1 + (\alpha \div 11.5^\circ)$; since the work performed in horizontal carriage of burdens is nearly equivalent to raising the total weight one foot in five, for which we have $\sin^{-1}\frac{1}{5} = 11.5°$. The art of securing best results in the use of animals drawing loads in vehicles of various sorts is that of so proportioning load, line of pull, weight of vehicle, and speed of travel as to permit the animal to take its natural gait and best total effort under load, this effort being measured at the traces. Obviously, the lighter the wagon or cart it is found practicable to employ for the proposed load the better. Also, the larger the loads transported in one vehicle the better, as a rule; and thus, in all large operations, heavy loads in comparatively light carriages, and drawn by numbers of animals, give most economical results. As inclines decrease the useful work in rapid proportion with their rise, the production of level and smooth roads is an essential to economy. This is illustrated in the case of railways, where enormous sums are expended to insure straight, level, and smooth tracks. For men the treadmill, and for animals well-constructed "horse-powers," embodying the same principles of construction, give highest efficiency as measured by the work performed per day, in foot-pounds or kilogrammetres. Walking up a moderate incline carrying only the weight of the body is the most easy and natural of all methods of employing its power. This system is capable, however, of but very limited application in ordinary industrial work. It is oftenest seen in use in threshing-machines and other agricultural apparatus.

26. In Selection and Care in the employment of men and animals, the engineer is compelled to regard them as machines, to be selected with careful reference to the exact requirements of the work proposed to be done, to be handled in such manner as to give him maximum returns for his expenditures, and to be made to produce large commercial results throughout the period of their use. Fortunately, a wise regard of these principles results in giving the man or the animal highest health, in insuring him against overwork, and in encouraging high spirits by the supply of good food, permitting ample allowance for sleep and rest, and prolonging the period of useful life. In exceptional cases the animal machine must be exposed to deleterious influences, overstrain, or liability to serious accident; but these cases can usually be made extremely rare by intelligent engineering, and, in the case of man at least, the individual so exposed receives what is thought by him satisfactory compensation for the risks so taken.

In the selection of the man or animal for a specified work, the wise and experienced engineer, or his contractor, looks for light, active, spirited creatures for light work, heavy and powerful, though slow, animals for heavy work, and can usually find just that combination of qualities of body, intelligence, and spirit which his experience teaches him are best for the specified purpose. The racehorse, the roadster, the hackney, and the draught-animal all have their special parts to perform. Neither can satisfactorily do the work of the other; and the same is true of man, whether performing purely manual labor, working at a trade, or taxing his mind in the direction of an industrial army or otherwise. For every sort of task there is to be found a kind of man specially and peculiarly adapted to its successful accomplishment. Not only individuals, but families, tribes, and even races, adapt themselves, through natural constitution and peculiar characteristics of body and mind, to special kinds of work. Among the best species, races, tribes, or families, individuals may always be found especially well fitted to perform a specified work; and among such individuals, the age, state of health, conditions of environment, may produce serious differences at different times. All such variations are noted by the engineer and serve as the basis of his judgment in apportioning work, in assigning duties, and in determining compensation.

The work once assigned, the person in charge should be expected not only to see that the conditions of best effect are adhered to, strictly and continuously, but to arrange the times and methods of serving meals, the character, amount, and method of preparation of the dietary with a view to insuring the best possible conversion of its potential energy into work and at minimum cost consistent with highest results. Even satisfaction with the bill-of-fare, by promoting appetite and digestion, is an element of success, with animals as well as with men. Periods of rest should be so arranged that the food may be taken neither when fatigue nor immediately succeeding labor may interfere with its digestion. Two meals, even one hearty and well-digested meal per day is sometimes found, for this reason, better, on the whole, than a larger number resulting in impaired digestion and defective nutrition. In hot climates, particularly, natives are observed often to be well satisfied with a single meal, taken after a hard day's work; the precaution being observed to secure an hour of complete rest before taking it. Hard-worked stage-horses, fed an hour before going upon the road in the morning with a warm mixture of cut hay and corn-meal, moderately wet, and fed again after their rest on coming in at night, have been found to do the season's work better than when given a third meal at noon. The meal should, in all cases, consist of nutritious food of proper composition, and in ample quantity to satisfy the appetite, without permitting excess.

No less essential in securing the most that can be obtained from the working man or animal is the provision of suitable clothing and housing. Weather-tight, warm, thoroughly comfortable, and yet well-ventilated stables are essential to highest economy in the employment of animals; and the same care, precisely, is demanded in providing for men, with the additional requirement that everything within reason that shall conduce to content and cheerfulness, high spirits, ambition, and an inclination to do their best work should be conscientiously provided.