will be taken beneath your feet." But a position, though airy, may yet be impregnable. There are those present who will recollect how the highest placed forts of that town were never taken, but continued to the last to answer shot for shot, and shell for shell, to the Allies. The attacking forces knew not the strength of these north forts till they entered them, but when they entered them, they entered them as friends.

ON THE RELATION OF FOOD TO WORK DONE BY THE BODY;

AND ITS BEARING UPON MEDICAL PRACTICE.

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INTRODUCTORY.

MAN, like other animals, is born, grows, comes to maturity, reproduces his like, and dies; passing in his lifetime through a cycle of changes that may be compared to a *secular* variation, by a metaphor borrowed from the science of astronomy; while, in his daily life, he passes through a smaller cycle of changes that may be called *periodic*.

From the time of the publication of Bichat's *Essay on Life and Death*, it has been admitted that man and other animals possess a double life, *animal* and *organic*, presided over respectively by two distinct, though correlated, centres of nervous force; of these, one *thinks, moves, and feels*; the other merely *cooks*, receiving the food supplied, changing and elaborating it into elements suitable for the use of the animal life.

In the lower forms of animals, the organic life becomes almost co-extensive with the whole being of the creature, which simply digests, assimilates, and excretes, but barely feels or moves. In the higher forms of animals, and more especially in man, the animal life dominates over the organic life, which becomes its slave; and it exhibits the remarkable phenomena of *mechanical force, of geometrical instinct, of animal cunning, and finally, in man himself, produces intellectual work*, rising to its highest form in the *religious feeling* that recognises its great Creator, and bows in humility before Him. It is a simple matter of fact, and of every day observation, that all these forms of *animal work* are the result of the reception and assimilation of a few cubic feet of oxygen, a few ounces of water, of starch, of fat, and of flesh.

The general question of the relation of Food to Work would involve a consideration of the possibility of throwing a bridge across the gulf that separates the organic from the animal life, so as to connect the products of nutrition (taken in its widest sense) with the work of every kind accomplished by the animal life, whether mechanical or intellectual. We resemble the spiders of the heather on a summer morning, that float their gossamer threads into the air from the summit of a branch, in the hope that some stray breath of wind may fasten it to a neighbouring tuft, and enable the hungry speculator to extend the range of his rambles and his chances of food. Already a few feeble threads connect the chemistry of our food with the *mechanical work* done by our muscles. When these have been securely fastened, from the higher vantage-ground acquired, our little bridge of knowledge may possibly be extended to embrace the phenomena of the geometrical instinct of the bee or the cunning of the beaver; and our successors may even dare to speculate on the changes that converted a crust of bread or a bottle of wine, in the brain of Swift, Molière, or Shakespeare, into the conception of the gentle Glumdalclitch, the rascally Sganarelle, or the immortal Falstaff. At present, such thoughts would be justly regarded as the dreams of a lunatic, and I must claim your indulgence for having mentioned them. The history of science is, however, filled with such dreams; some never realised; others converted by time into realities so commonplace that the genius of their originators is habitually forgotten or underrated.

During childhood and youth, the food that we eat is used for the double purpose of building up the tissues of the bones, the muscles, the brain, and other organs of the body, and of supplying the force necessary for work done, whether mechanical or intellectual. In adult life, the first use of food almost disappears; for the bones, the muscles, the brain, and other organs, have already reached their full development, and act simply as the media of communication between the food received and the work developed by it.

Let us take, as illustrations, the muscles and brain, regarded as the organs by means of which mechanical and intellectual work is done. These organs resemble the piston, the beam, and the fly-wheel of the steam-engine, and, like them, only transmit or store up the force com-

municated by the steam in one case, and by the products of the food conveyed by the blood in the other case. The mechanical work done by the steam-engine must be measured by the loss of heat experienced by the steam in passing from the boiler, through the cylinder, to the condenser; and not by the loss of substance undergone by the several parts of the machinery on which it acts. In like manner, the mechanical or intellectual work done by the food we eat is to be measured, not by the change of substance of the muscles or brain employed as the agents of that work, but simply by the changes in the blood that supplies these organs—that is to say, undergone by the food used, in its passage through the various tissues of the body, before it is finally discharged in the form of water, carbonic acid, or urea.

The Divine Architect has so framed the animal machine, which moves and thinks, that the same blood, which by its chemical changes produces movement and thought, also repairs the necessary waste of the muscles and brain, by means of which movement and thought are possible; just as if the steam that works an engine were able, without the aid of the engineer, to repair the wear and tear of its friction and waste spontaneously. But no greater mistake is possible in physiology, than to suppose that the products of the changes in the blood, by which mechanical or intellectual work is done, are themselves merely the result of the waste of the organs, whether muscles or brain, on the exercise of which that work depends.*

The ancients, who derived all their knowledge from observation, and not from experiment, were well aware of the double duty imposed upon food in early life—of producing both the *secular* and the *periodic* variations of the body; or, in other words, of promoting growth, and of developing work. Their practical knowledge is summed up by Hippocrates in the aphorism, "Old men bear want of food best; next, those that are adults; youths bear it least, more especially children; and, of these, the most lively are the least capable of enduring it."†

The food consumed in twenty-four hours, including air and water, undergoes a series of changes of a chemical character before leaving the body, in the form of one or other of its excretions. Some of these changes develop force, and others expend force; but the algebraic sum of all the gains and losses of force represents the quantity available for work. This work must be expended as follows:—

1. The work of growth (*secular*).
2. The work of maintaining heat (*periodic*).
3. Mechanical work (*periodic*).
4. Vital work (*periodic*).

During childhood and youth, the work of growth is positive; for a certain proportion of the food used is employed in building up the tissues of the body, instead of being expended in actual work; it is, in fact, "stored up" in the body, as *vis viva* is stored up in the fly-wheel of machinery, and constitutes a reservoir of force that may be called upon at an emergency requiring sudden expenditure of force, or in case of illness, or in the gradual wasting of old age.

In adult life, and in old age, the work of growth ceases completely, except so far as is necessary to repair, from day to day, the small wastes of the organs employed in work; so that nearly the whole of the food employed is expended on the *periodic* work of the body.

Hence we can readily see the reason for the aphorism which asserts that food is more necessary for the young than for the old, and more required by those of a lively disposition, either of mind or body, than by others.

Hippocratic Doctrine of Innate Heat.

Hippocrates was well aware of the connexion between food and animal heat, although he erroneously regarded the animal heat as an innate property of the body that caused an appetite for food, instead of being itself produced by food. If we transpose his cause and effect, *mutatis mutandis*, all his maxims as to animal heat are true. Thus he says:

"Growing animals possess most innate heat, hence they require most

* The very skill with which provision is made for the repair of the waste of the organ used as the instrument of work, may mislead the observer into supposing that the work itself may be measured by the waste of its instrument. Thus, it has been shown by Mr. A. Macalister, that the heart, which has imposed upon it the necessity of working day and night without ceasing, during life, is furnished with double the usual supply of blood through the coronary arteries, which are injected twice for every single beat of the heart. If, indeed, it were possible to assume that all muscles wasted equally for equal quantities of work, and also to measure separately the products of that waste, we might then assume the waste of the organ as the measure of its work. Neither of these assumptions, however, can be admitted; for it can be shown that different muscles act under different conditions, more or less advantageously, so that equal wastes would represent unequal works; and also, it is impossible to separate in practice the products of waste of muscles from those of the general changes of the blood.

† Γέροντες εὐφορώτατα νηστεῖν φέρουσι, δεύτερον οἱ καθεστῆκότες, ἥκιστα πειράκια, πάντων δὲ μάλιστα παῖδια, τούτων δὲ αὐτῶν ἂν τίχῃ αὐτὰ ἑαυτῶν προθυμότερα εἶναι. —Aph. I, 13.

food; . . . but the old have least heat, and therefore require the least fuel.*

"The cavities of the body are naturally warmest in winter and spring. . . . In these seasons, therefore, most food must be given; and, since there is more innate heat, more nourishment is required, as may be seen in youths and athletes."†

These maxims, when translated into modern language, express the well known fact, that the chemical changes of food that take place in the body produce animal heat; and that the necessity for food to supply mechanical work is greatest with the young and active, while the necessity for the production of animal heat is the greatest in the cold seasons of the year. The direct connexion of food with mechanical work is expressed in the following maxims: "There should be no labour when there is hunger."‡ And its converse, "Let labour precede meals."§

On principles such as those just given, the training of the athletes was conducted; and they were compelled to undergo a regular course, commencing with blood-letting and active purgation,|| and consisting of systematic muscular exercise suited to the nature of the contest intended, accompanied by a dietary, of which the chief ingredients consisted of biscuits and pigs' kidneys, washed down by a minimum of water.

It is, truly, not much to be wondered at, that those who survived the training were formidable in the boxing-ring or racecourse.

The relation of animal heat to respiration is referred to by Hippocrates in a remarkable maxim: "Those persons have the loudest voices who have most [innate] heat, for they inspire the largest quantities of the cold air; and the product of two great quantities must be itself great."¶

Galen believed the heart to be the centre of "innate heat"; but he was well aware that increase or diminution of respiration caused increase or diminution of heat, and was intimately connected with it. Thus he says: "Since, therefore, the heart is, as it were, the hearth and fountain of the innate heat, with which the animal is pervaded," etc.** "The necessity for respiration is the greatest and most imperious guard of the innate heat."†† "Those persons in whom the innate heat has been much cooled, breathe but little and slowly."‡‡

Lavoisier's Theory of Animal Heat.

The doctrine of "innate" heat, taught by Hippocrates and Galen, ruled in Medicine for 1500 years after Galen's death; until it received its death-blow from the genius of Lavoisier, who demonstrated in his celebrated memoir read before the French Academy of Sciences in 1783, that the source of animal heat is to be found in the combustion of the carbon of the body by the oxygen of the air received into the lungs by respiration. Lavoisier's experiments were repeated and confirmed in 1822 by Dulong and Despretz; and have formed the starting point for all modern investigations on the relation of food to work.

As already stated, the work done by food in the body may be divided into—1, the work of growth; 2, the work of animal heat; 3, mechanical work; 4, vital work.

Lavoisier arranged his experiments so as to exclude almost all kinds of work done, except that of animal heat. A Guinea-pig was placed under a bell-glass inverted over a surface of mercury, and a current of fresh air was allowed to circulate through the apparatus, being passed at its final exit through tubes containing caustic potash, which arrested the carbonic acid produced by the animal. In this manner, it was easy to ascertain the carbonic acid excreted, by the increase in weight of the tubes of caustic potash during the experiment.

Lavoisier found that his Guinea-pig, in ten hours, burned, on the average, 3.333 grammes of carbon; and this quantity of carbon he estimated from other experiments as capable of melting 326.75 grammes of ice at the freezing temperature. The same Guinea-pig was then placed in an ice calorimeter, and left in it for ten hours, during which time the

heat of its body was found to have melted 402.27 grammes of ice at the freezing temperature.

If we use, instead of the co-efficient of combustion of carbon employed by Lavoisier, that now generally adopted from the experiments of Favre and Silbermann, the quantity of melted ice represented by 3½ grammes of carbon would become 364.78 grammes, instead of 326.75 grammes.

We are, therefore, entitled to say that the heat of combustion of expired carbon determined by Lavoisier is equal to

$$\frac{364.78}{402.27} = 90.68 \text{ per cent.}$$

of the animal heat developed, which is regarded as 100.

Two years later, in 1785, Lavoisier laid before the Royal Society of Medicine of Paris an account of further experiments, also conducted on the breathing of Guinea-pigs, by which he showed, that of 100 parts of oxygen absorbed by those animals, 81 only reappeared in the form of carbonic acid, and 19 parts disappeared altogether. Lavoisier considered that these 19 parts of oxygen were employed in the body in the combustion of hydrogen, the product of such combustion being water.

If we use Lavoisier's data just given, and the known atomic weights of carbon, oxygen, and hydrogen, we shall have, for 81 parts of oxygen in the form of carbonic acid, and 19 parts of oxygen in the form of water, the following quantities of carbon and hydrogen consumed by the respiration of a Guinea-pig in the same time.

$$\text{Carbon} = \frac{6 \times 81}{16}$$

$$\text{Hydrogen} = \frac{19}{8}$$

Multiplying these numbers by the heat co-efficients of Favre and Silbermann, we find—

$$\text{Heat produced by carbon} = \frac{6 \times 81}{16} \times 8080$$

$$\text{Heat produced by hydrogen} = \frac{19}{8} \times 34462$$

It has been already shown that the heat developed by the combustion of carbon in Lavoisier's experiment amounted to 90.68 per cent. of the heat emitted by the animal; hence the heat produced by the combustion of the hydrogen will amount to

$$90.68 \times \frac{19 \times 34462}{8} \times \frac{16}{6 \times 81 \times 8080}$$

= 30.24 per cent. of the heat emitted by the animal. By adding together the heats due to the carbon and hydrogen, we find that Lavoisier's experiments, when fairly interpreted by the data of modern science, give the following results.

Heat produced by the combustion of carbon and hydrogen... 120.92
Animal heat 100.00

Finally, in 1789, Lavoisier published further experiments, by which he showed conclusively that the consumption of oxygen by the body is notably increased by three causes:

1. By a lowering of the external temperature.
2. By the act of digestion.
3. By muscular exercise.

The experiments of Lavoisier were repeated in 1822 by Dulong and Despretz, and their results, when corrected, like those of Lavoisier, by using the modern heat co-efficients of carbon and hydrogen, are as follows. The mean of Dulong's experiments on sixteen animals and birds is 90.6 per cent. of the animal heat given out; the lowest number, 85.5, belonging to a kitten sixty days old; and the highest number, 99.4, belonging to a puppy fifty days old. M. Despretz obtained an average of 92.3, from sixteen mammals and birds; his highest number being 101.8, derived from an old female rabbit; and his lowest number being 84.2, derived from four owls.

The foregoing experiments left no doubt remaining in the minds of men of science as to the substantial truth of Lavoisier's doctrine of animal heat; and led immediately to a number of supplementary experiments, amongst the most remarkable of which were those of Regnault and Reiset.

Regnault directed his attention especially to the distribution of the oxygen absorbed by animals, between the carbon and hydrogen of their blood, or tissues, which had been laid down by Lavoisier in the proportion of 81 to 19. He found that the proportion was not a fixed one, but varied with the food in a very instructive manner.

* Τὰ αὐξανόμενα πλείστον ἔχει τὸ ἐμφυτον θερμὸν, πλείστης οὖν δεῖται τροφῆς..... γέροντι δὲ ὀλίγον τὸ θερμὸν, διὰ τοῦτο ἔρα ὀλίγων ὑπεκκαυμάτων δέονται.—Aph. I, 14.

† Αἱ κοιλίαι χειμῶνος καὶ ἡρος θερμύταται φύσει ἐν ταύτησιν οὖν τρεῖς ὄρησι καὶ τὰ προσάσματα πλείω δότον. Καὶ γὰρ τὸ ἐμφυτον θερμὸν πλείστον ἔχει, τροφῆς οὖν πλείονος δέονται, σημείον αἱ ἡλικίαι καὶ οἱ ἀθληταί.

‡ Ὅκου λιμὸς, οὐ δεῖ πονεῖν.—Aph. II, 16.

§ Πόνοι σιγῶν ἡγέσθωσαν.—Epid. VI, Sect. iv, 28.

|| Ἐλκεα ἐκφύουσιν ἢν ἀκάθαρτος ἔων πονήσῃ.—Epid. VI, Sect. v, 32.

¶ Οἷσι πλείστον τὸ θερμὸν, μεγαλοφρονότατοι, καὶ γὰρ ψυχρὸς ἀήρ πλείστος. δύο δὲ μεγάλων μεγάλα καὶ τὰ ἐκγόνα γίνονται.—Epid. VI, Sect. iv, 22.

** ἐπεὶ τοῖνον ἡ καρδία τῆς ἐμφύτου θερμότητος, ἣ διοικεῖται τὸ ζῶον, οἷον ἔστι τὸ τίς ἐστι καὶ πηγὴ κ. τ. λ.—De usu partium, Lib. vi, ch. 7.

†† ἡ χρεῖα τῆς ἀναπνοῆς ἡ μεγίστη μὲν καὶ κυριωτάτη φυλακὴ τῆς ἐμφύτου θερμότητος ἐστίν.—De diff. Resp., Lib. i, ch. 4.

‡‡ ὥσπερ καὶ ὅταν μικρὸν ἐισπνέωσι καὶ βραδέως, οἷς ἱκανῶς ἐψφύεται τὸ ἐμφυτον θερμὸν.—De diff. Resp. Lib. i, ch. 20.

The average of his experiments on fourteen animals, including worms, lizards, and insects, as well as birds and mammals, was

Oxygen combined with carbon80.7

Oxygen combined with hydrogen.....19.3

a result identical with that found by Lavoisier. The highest proportion of oxygen combined with hydrogen, occurred in the case of chickens fed on meat, and amounted to 32 per cent.; and the lowest proportion occurred in the case of rabbits fed on bread and oats, and amounted to 1 per cent. only.

Still more recent experiments, made with improved apparatus and methods by Pettenkofer and Voit, in Munich, show, like those of Regnault, that the proportion of the oxygen employed in forming carbonic acid, to the whole oxygen absorbed, varies with the food, ranging in the case of a large dog from 52.4 to 148.2, according as the animal was kept altogether without food, or fed upon a mixed diet of meat and sugar. These investigations have also shown that, under ordinary conditions, it is probable that a dog consumes nearly all the oxygen absorbed in the formation of carbonic acid.

Before leaving the subject of animal heat, it is worth while to estimate its amount in a manner that will bring it into comparison with ordinary mechanical work.

In Lavoisier's experiment with the Guinea-pig, 402.27 grammes of ice were melted in ten hours; from this fact, we find, assuming the latent heat of ice at 142 deg. Fahr., and 772 as Joule's co-efficient for converting British heat-units into foot-pounds,

Mechanical work equivalent to the daily animal heat of Lavoisier's Guinea-pig=

$$\frac{402.27 \times 24 \times 142 \times 15.432 \times 772}{7000 \times 10} = 233310 \text{ foot-pounds.}$$

As the average weight of a Guinea-pig is 4 lbs., the preceding amount of work, representing animal heat, would be sufficient to raise the weight of the animal through a vertical height of

$$\frac{233310}{4 \times 5280} = 11.05 \text{ miles.}$$

Ranke has shown, by experiments made upon himself, under various conditions of food and fasting, by means of Pettenkofer and Voit's apparatus, that his daily excretion of carbonic acid varied from 660 grammes to 860 grammes. His weight was 67 kilogrammes; from which fact, and the assumption that an English mile is 1600 meters, we obtain, employing the contents already given, the height through which the combustion of this quantity of carbon would raise the weight of 67 kilogrammes in 24 hours—

$$\frac{760 \times 6 \times 8.080 \times 423}{22 \times 67 \times 1600} = 6.609 \text{ miles.}$$

The extreme values of the carbonic acid excreted; viz., 660 grammes and 860 grammes, would correspond to the heights of 5.74 miles, and 7.48 miles respectively.

Pettenkofer and Voit succeeded in producing a range of carbonic acid excreted by a large dog, weighing 33.3 kilogrammes, from 289.4 grammes to 840.4 grammes; the minimum corresponding to the tenth day of fasting from solid food, and the maximum corresponding to a diet of 1800 grammes of meat, 350 grammes of fat, and 1410 grammes of water.

It may be easily shown, by a calculation similar to the foregoing, that these excretions of carbonic acid correspond to the mechanical works of lifting the weight of the dog through vertical heights of 5.03 miles, and 14.62 miles respectively.

Combining together the preceding results, and expressing them all in the natural units of the weights of the animals lifted through a height, we find—

Work due to Animal Heat.

1. Guinea-pig	11.05 miles.
2. Man	5.74 „
3. Man	7.48 „
4. Dog	5.03 „
5. Dog	14.62 „

Mean..... 8.784 „

Source of Muscular Work.

As soon as it was satisfactorily established by Lavoisier and his successors that the natural combustion of carbon and hydrogen in the blood was sufficient, and rather more than sufficient, to account for the animal heat, it became a matter of great interest to physiologists to ascertain, if possible, how much of the work developed in the blood by chemical changes is employed in producing animal heat, how much in mechanical work, external and internal, and how much in vital or mental operations.

At the outset of this inquiry, it received a misdirection from the conjecture thrown out by Liebig, that the excretion of nitrogen (in the form of urea) gave necessarily the measure of the wear and tear of the muscular tissues themselves, which are composed of proteinic or nitrogenous compounds. This conjecture led to Liebig's celebrated classification of food into *Heat-producing* and *Flesh-forming* foods, which has been unhesitatingly received until lately, in this country, by physiologists and physicians.

Before investigating the truth or falsehood of Liebig's theory, it is worth while to state the most recent results obtained as to the muscular work per day of which man is capable.

From numerous observations, of which some were made by myself on the daily labour of hodmen, paviours, navvies, and pedlars, I have obtained the following mean:—

Daily labour of Man = 353.75 ft. tons = 109549 *kilomètres*.

This quantity of work is the exact equivalent of the work done by a man of 150 lbs. weight in climbing through one mile of vertical height; and is, as I have already shown, less than *one-eighth* part of the work expended in producing and maintaining animal heat.

Even if we add to the external muscular work that of circulation and respiration, which may be estimated at 133-foot tons, the whole work done by the muscles, voluntary and involuntary, of a hard-worked labourer, will amount to less than *one-sixth* of the work expended in maintaining the temperature of his body at 100° F.

I was led to believe, from my investigations as to the quantity of urea excreted in various diseases, that a certain minimum quantity equivalent to 2 grs. per pound avoirdupois of body weight, was excreted quite independently of muscular exertion, and I proved that death was preceded in many chronic diseases by a fall in the urea excreted to 2 grs. per pound. These investigations were made chiefly on patients dying of advanced kidney-disease, in which the excretion of albumen had nearly or altogether ceased, and on patients dying of phthisis.

Pettenkofer and Voit found that the excretion of urea in a dog reduced to 29 kilogrammes by 10 days' fast was reduced to 8.6 grammes. And, since

$$\frac{29 \text{ kilogrammes}}{8.6 \text{ grammes}} = \frac{63.8 \text{ lbs.}}{132.7 \text{ grs.}}$$

Excretion of urea = 2.08 grs. per lb. of body weight.

Ranke obtained a precisely similar result from observations made upon himself, after long fasting, continued for several days.

If these views be well founded, it is plain that part only of the urea excreted can be regarded as due to muscular exertion, for 2 grs. per lb. (or 300 grs. for a man weighing 150 lbs.) must be set aside as a constant due to vital work, independent of muscular work altogether. Hence it would follow, supposing the muscular exertion to be measured by the increased excretion of urea produced by it, that the urea will not increase as fast as the muscular exertion, but it ought to increase regularly, although at a slower rate. With a view to settle this important question, I devised the following observations upon myself in the month of July, 1866, which prove conclusively that an increase of muscular exertion, amounting to fourfold, is not accompanied by any corresponding increase in the excretion of nitrogen, in the form of urea.

I had previously ascertained by repeated experiments, extending from 1860 to 1865, that my excretion of urea (under ordinary conditions as to exercise, which did not exceed 5 miles per day), ranged from 465.09 grs., to 537.47 grs. per day; the mean being 501.28 grs.

This quantity of urea I regarded as my natural physiological average, and it was so well established, that I thought I should obtain an important result by comparing it with the average found from several days of unusual muscular exertion. I accordingly walked for five consecutive days in the hilly districts of Wicklow, noting carefully the horizontal distance traversed each day, and the vertical height traversed up and down. The vertical heights were reduced to horizontal distances, on the assumptions (which are well founded) that 20 is the proper coefficient for converting one into the other, and on the assumption that the work of descent is half the work of ascent.

During the five days of observation the work done, expressed in horizontal miles of walking, was as follows:—

	Miles.
<i>First Day.</i> —Miles walked	11.4
Height ascended	1800 ft. = 10.2
	21.6
<i>Second Day.</i> —Miles walked	12.0
Height ascended	2400 ft. = 13.7
	25.7

Third Day.—Miles walked	11.6
Height ascended	1400 ft. = 8.0
	19.6
Fourth Day.—Miles walked	9.3
Height ascended	1400 ft. = 8.0
	17.3
Fifth Day.—Miles walked	10.4
Height ascended	1600 ft. = 9.1
	19.5

From the preceding statement it follows that the average work done each day was 20.74 miles of horizontal walking—the result of which upon the urea excreted was to be compared with the result already mentioned, as a physiological constant determined under circumstances in which the daily muscular work never exceeded 5 miles of horizontal walking.

In order to determine the urea, I collected each day all the urine passed, and kept one-fifth part of it; and at the close of the fifth day examined the mixture formed from the five days' urine.

It was found to contain 501.16 grs. of urea per day—a result identical with the physiological quantity previously found by me under totally different conditions, viz., 501.28 grs.

I was much surprised at this result, for I had previously believed in the theory laid down by Liebig, which attributed the excretion of urea to the disintegration of muscular tissue.

It might be objected to the preceding reasoning that there can be no doubt as to the capability of the combustion of proteinic compounds represented by 501.28 grs. of urea excreted to produce mechanical force sufficient to explain the muscular exertion of walking 20 or 21 miles per day; as may be shown in the following manner:—

1. The urea excreted bears to the proteine consumed the proportion or 24 to 79; as appears from their chemical compositions—viz.,

Urea	C ² H ⁴ N ² O ³	60
Proteine	C ²⁸ H ²⁷ N ⁴ O ¹⁹	395

2. In 100 parts of proteine there are 53.7 parts of carbon, and 7 parts of hydrogen; the total heat due to the combustion of 1 grm. of proteine is, therefore,

	Heat-units.
0.537 gramme of Carbon	4.3389
0.070 gramme of hydrogen	2.4123
	6.7512

This number, 6.7512, represents the maximum quantity of heat-units* that could be produced by the combustion of 1 gramme of proteine; but the term depending on hydrogen in it should be reduced to five-ninths of its amount, in consequence of the hydrogen already combined with oxygen in the proteine. Hence we find—

Combustion of 1 gramme of Proteine.	
Carbon	4.3389 heat-units.
Hydrogen	1.3402 „
	5.6791

3. In 100 parts of urea there are 20 parts of carbon, and 6½ parts of hydrogen; the total heat, therefore, due to the combustion of 1 gramme of urea is

0.20 gramme Carbon	1.6160
0.067 gramme Hydrogen	2.3089
	3.9249

The term depending on hydrogen, in this result, should be reduced to one-half, in consequence of the hydrogen already combined with oxygen in the urea. Hence we find—

Combustion of 1 gramme of Urea.	
Carbon	1.6160
Hydrogen	1.1544
	2.7704

4. From the three preceding statements, it is easy to see that, for every gramme of proteine consumed, 0.8416 heat-units are contained in the urea excreted; so that

The digestion of 1 gramme of proteine gives out 4.8375 heat-units.

* Heat-unit = 1 kilogramme of water raised to 1° centigrade.

It is easy to see that 501.23 grs. of urea excreted correspond to 1650 grs. of proteine in the food, or to 106.92 grammes; and the total work due to the digestion of this quantity of food may be found by multiplying it by the "Digestion-coefficient" already found, and by 423, which is Joule's coefficient for converting heat-units into kilogrammeters. Hence we have

Work due to production of 501.28 grs. of urea = 106.92 × 4.8375 × 423 = 218786 kilogrammeters = 704 foot-tons.

This amount of theoretical work produced by nitrogenous food is more than double the work actually done during the walking excursion.

The average work was 20.74 miles horizontal per day, which may be considered as the exact equivalent of lifting my weight (knapsack and clothes included = 150 lbs.) through one mile of vertical height. Hence the work actually done by me was

$$\frac{150 \times 5280}{2240} = 354 \text{ foot-tons.}$$

I have elsewhere shown that the work done by the heart per day amounts to 122 foot-tons, which should be added to the external work, as well as the unknown work due to the muscles used in respiration, probably amounting to one-sixth of the heart's work, or 21 foot-tons. Adding these quantities, we find—

External Work	354 foot-tons.
Circulation and Respiration ..	133 „

487 foot-tons.

This quantity represents 69 per cent. of the applied work, which was shown to be 704 foot-tons,

The amount of muscular work accounted for is 354 foot-tons, which is almost exactly half the whole theoretical work supplied by the food that goes to form the urea—viz., 704 foot-tons; but it has been already shown that 2 grs. of urea per pound of body-weight is required to maintain the vital work, including circulation and respiration. This would give from 240 grs. to 260 grs. of urea out of the 501 grs. available for vital work; so that one-half of the available work may be considered as expended on vital work, and the other half as expended on external muscular work. This supposition, however, requires us to believe that the muscles act without loss by friction. This is not admissible; for I have elsewhere endeavoured to show that there is a loss in the force applied by the muscles of various animals, in consequence of the friction of their tendons amounting—

In Man to	35 per cent.
In the Mastiff to	41 „
In the Kangaroo to	61 „

Hence it may be regarded as certain, that the available force represented by 501 grs. of urea is not sufficient to account fully both for vital work and for the external mechanical work expended by me during the experiments just described.

(To be concluded.)

PARASITIC AFFECTIONS OF THE URINARY AND GENITAL ORGANS.—Dr. Salisbury, whose views on the cryptogamic origin of measles, intermitent fever, and venereal diseases, are well known to American and British practitioners, has published, in the April number of the *American Journal of Medical Science*, an interesting paper on vegetable and animal parasites found in certain diseased conditions of the urinary and genital organs. When the general system is out of order, and the secretions of the pelvic mucous membranes abnormal, the parent epithelial cells of the uterus, vagina, kidney, bladder, and urethra, afford a fertile soil for the development of low cryptogamic forms, which develop and multiply with great rapidity. The fungoid and algoid spores thus developed produce irritation, set up excessive cell-activity and secretion, and finally result in the formation of pathological products. Fourteen forms of cryptogamic vegetation have been observed by Dr. Salisbury in abnormal conditions of the urinary and genital organs. Among these are included the *Botrytis infectans*, the fungus which produces the so-called potato-rot; and the *Spharotheca pyra*, the active agent in blight of apple and pear trees. The first mentioned parasite sets up great irritation along the urinary passages, and is frequently associated with severe hæmaturia. Animal organisms of inferior types have also been found multiplying rapidly in vaginal discharges and in unhealthy urine. The following are described by Dr. Salisbury:—1. The *Trichina cystica*, a small parasite found in the bladder; 2. A species of vibrio, resembling that found in vinegar, which is present in urine; 3. The *Trichomonas vaginæ*. 4. The *Ciliaris bicaudalis*, a single oval and ciliated cell, furnished with two hair-like caudal prolongations. 5. The *Trichomonas irregularis*, an oval non-ciliated cell, furnished with a beak and two thin appendages. The last four parasites were found in abnormal urine and vaginal discharges.