WASTE AND REPAIR.

BY

JOHN GRAY M'KENDRICK, M.D.,

FELLOW OF THE ROYAL COLLEGE OF PHYSICIANS, AND OF
THE ROYAL SOCIETY OF EDINBURGH,
AND PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF GLASGOW.

WASTE AND REPAIR.

BY

JOHN GRAY M'KENDRICK, M.D.,

FELLOW OF THE ROYAL COLLEGE OF PHYSICIANS, AND OF
THE ROYAL SOCIETY OF EDINBURGH,
AND PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF GLASGOW.

A Lecture delivered in the City Hall, on 10th October, 1881, being the first of a Course of Lectures on Health, under the auspices of the Trustees of George Combe and the Young Men's Christian Association.

WASTE AND REPAIR.

BY PROFESSOR M'KENDRICK.

1. THE physiological subject I have chosen to bring before you this evening may be regarded as introductory to the present Course of Lectures. Physiology is the science which treats of all the changes occurring in the living body in a state of health, and it is evident that we must know a great deal about these changes before we can arrive at a knowledge of the conditions of well-being. Thus, physiology is the basis of all rational efforts to maintain the health of individuals and of communities, and of all attempts to cure or alleviate disease. I think, therefore, that a physiological subject may not inappropriately begin the present course of Lectures, which are intended to give practical information to our working classes on some of the conditions of health, and on what they may be able to do, in their own sphere, and without professional assistance, in the treatment of common accidents or of common ailments.

2. The living human body, the living body of any animal, and in a more limited sense the body of every living plant, may be regarded as a machine for the performance of work. Now, by work, I mean the overcoming of resistance. When I lift a weight I overcome the resistance offered by the action of gravity on the weight, and when I wind up the main spring of a watch I overcome the resistance of the elasticity of the spring; in both cases I do work. Again, if we light the fire under the boiler of a steam

engine, steam is generated; by its expansion pistons and wheels are moved, mechanical work is done in the pulling of heavy weights, or in the revolution of numerous shafts, and the movements of intricate machinery. In a diverse way, the human body is constantly doing work. The limbs are moved by muscular action, so as not only to carry the weight of the body from place to place, but even to lift loads, wield hammers, and otherwise to act on external matter; the heart beats without intermission, and drives the blood through the body; the chest heaves up and down in respiration; the brain thinks and feels; and all the elaborate processes of digestion, of absorption, of secretion, and of excretion, are modes of doing work. In all these operations work is done in the sense of overcoming the resistance of external forces, and the body may be thus regarded as a machine.

3. Now, if you think of any machine with which you are familiar, you will see; *first*, that it gets its power of doing work from without; and, *second*, that it is always undergoing a certain amount of tear and wear. Let us take, for example, the case of an ordinary steam engine. Suppose it to be finished and ready for work, with the boiler supplied with water, and the fire ready to be lit. In such circumstances, of course, it would not move, and no work would be done. It must receive energy in the way of heat from without. Light the fire, convert part of the water into steam, let this steam behind the piston, and soon, if all the proper arrangements have been made, the machinery will begin to move, and the engine will do its work. Now, where did the power of doing work come from? Of course, you say, from the fuel of the furnace; but let us see precisely what this means. Say that the fuel was coal. Coal consists largely of carbonaceous matter. When coal is brought into contact with flame, it burns; that is to say, its carbon unites with oxygen from the air to form a gas called carbonic acid, and its hydrogen with oxygen to form water; at the moment of the union of the carbon and hydrogen with the oxygen, energy in the state we call heat passes into the water

in the boiler; and when this water has been sufficiently heated, it becomes a highly elastic gas which, by its expansive force, drives the piston of the engine. The energy, therefore, which drives the engine is derived from the chemical changes happening in the furnace. It does not much matter what these chemical changes are, provided heat is evolved by them. The energy, therefore, of the steam engine comes from without. In a sense it existed in the coal in the bowels of the earth and in the oxygen of the air; but we must not think of energy as something having a separate existence. The language of science simply implies that when these two substances, carbonaceous matter, as in coal, and oxygen, as in air, are brought together under suitable conditions, they unite to form compounds, and energy is there and then manifested in what we call heat, and this heat may be compelled to do work.

4. But let us look at the engine a little more closely. Suppose we work it for a considerable time, we find it undergoes tear and wear. The boiler plates become thinned, joints work loosely, pins or bolts get slackened, and many indications of waste occur with which engineers are more familiar than I am. It is clear that a state of things by and bye would occur which would make movement impossible. Repairs are from time to time required. This shows us that the machine has no power of self-repair. Now, this of course is quite obvious, but I allude to it to emphasise the distinction between such a machine and the living body, which we will see has the power of self-repair. The machine exchanges matter with the external world, no doubt; coals and water come in, and ashes, steam, and smoke go out; but no portion of the coals or of the water ever become part of the machine. The framework of the machine is distinct from the source of its energy and from the matter supplied to it.

5. One of the most remarkable peculiarities of the living body is that it is a *self-reparative machine*. Let us try to understand how this comes about. The body of every animal springs from a small microscopical particle of living matter, the ovum or egg, the

diameter of which in the human being is about $\frac{1}{120}$th of an inch. Wonderful as it may seem, in strangeness far surpassing the wildest imaginations of men, in mystery more profound than even that of death, the qualities both of race and of individual are transmitted by this minute germ. In favourable circumstances, it absorbs matter from the outside, grows, and becomes more and more elaborate in structure; tissues are formed of the most various character, and organs of the most diverse functions, until the completely mature body is the result.

6. Now, during all these transformations, where did the energy come from? No doubt some existed in the original germ, and was derived from the parent. It had the power of absorbing nutritious matter from the outer world, and of converting this nutritious matter into its own substance. Thus, it got both *matter* and *energy* from the medium in which it lived. Had no nutrient matter been supplied to it, the germ would have died. But by the matter and energy thus supplied, the little germ grew, and from it, as I have said, the complex body was evolved. One of the most striking illustrations of this phenomenon of development is the formation of the chick in an egg. Here, from a small germ, supplied with nutriment from the yolk and the "white," and with oxygen from the air through the porous shell, the fully formed bird is produced, having a complicated body formed of bones, muscles, skin, feathers, nervous system, and all the organs necessary for a bird's existence. We are so familiar with this phenomenon that it has almost ceased to interest us, and yet I know of nothing in the whole range of science more deeply interesting and suggestive.

7. But when the body has been fully formed, and has arrived, say, at the adult condition, you may ask, is it not then stationary; does not its matter now become permanent, as in the engine; and does the body now merely get energy from the matter introduced as food, just as the engine gets energy from the fuel? This is not so. Make a demand again on your own fund of observation.

During infancy and childhood, we see the body growing. It increases in size and weight, indicating that matter has been acquired. But even when adult age has been reached, we observe changes in the appearance of the body from time to time. The general form of the features alters; the contours of the limbs change; the bulk of the body varies. These are matters of common observation. If we weighed a man daily, even making allowance for possible errors, we would find his weight varying from day to day. In most cases a man will increase in weight up to the time of middle age; after which, unless in cases of obesity, the weight will slowly diminish until in old age a man may be only the shrunken vestige of his former self. All this shows that exchanges of matter are going on throughout life. Matter is taken up from the food and from the air, becomes part of the living body for a time, and then leaves the body to make room for other matter. The machine, though constantly working, is self-reparative, and, in fact, as we will see, it is by the very act of waste and self-repair that its functions are determined. Without waste and repair there would be no living action.

8. The *matter* of the body is derived from the food and drink we consume and the air we breathe. But whence is the *energy* derived? Whence comes the force that enables us to do our work? Now, of course, you can readily again answer, the food; but that answer is not sufficient for our purpose, as we wish to get a clear comprehension of the actual facts of the case. It is only in recent years that physiologists have been able, in this department of their science, to express the facts familiar to them in the language of exact science, and I will now try to explain to you where the energy comes from.

9. When we examine living beings of very low organisation, and when we examine living tissues in their simplest forms and in the most favourable conditions, we find (1) that they all require oxygen gas; (2) that they absorb or imbibe into their substance complex matters—such as albuminous matter, fat, sugar, &c., in

the form of food; (3) that they produce during vital activity other chemical matters of simpler constitution—such as carbonic acid, ammoniacal compounds, and water; and (4) that they always contain living matter, which is often called *protoplasm*. Now, these statements are true as regards all living things and all living tissues that have yet been examined; and the inference physiologists draw is that the phenomena of life occur in protoplasm, and are dependent on the chemical changes occurring between the matter of the food and the oxygen of the air, leading to the formation of those simpler compounds to which I have referred. Thus, living matter receives oxygen from the air and compounds from the food; it absorbs these and makes them part of itself, and then, when it performs its vital functions, chemical changes occur in it and waste matters are thrown out in the form of simpler substances. You see how much more complex this living machine is than the steam engine. The oxygen and the food we take into our body represent the fuel and the oxygen of the air in the furnace of the steam engine; but, in the engine, these never become part of the mechanism, whereas in living tissues they do. Now, just as in the engine the source of the energy was traced to the chemical changes in the furnace, so in the body all the energy may be traced to the chemical operations occurring in the living tissues. The heat of the body (which is one of the conditions of life), every muscular movement, every nervous action,—be it feeling, thinking, or willing,—are dependent on, and are produced by, the chemical changes occurring in the living tissues. Cut off the supply of oxygen, or the supply of nutrient matter, and all these operations, as physiological processes, cease. Living matter, oxygen, and nutrient matter, are the material basis of life; not the living matter alone, as is often said; but the interchanges amongst the three are the conditions of life, and also the conditions of all energy or power of work manifested by the body.

10. With the view of illustrating what I have just said, I now

ask you to study for a short time the changes occurring in *muscle.* Muscle is the contractile substance by which we move one part of the skeleton on another part. If I flex the arm, for example, the muscles in the front of the arm contract and move the bones of the forearm on the bone of the arm at the elbow joint. This contractile substance is not placed at random under the skin, but exists in masses, of various forms, appearing with constancy in the limbs, which are called by anatomists, *muscles,* and to each of which they have attached distinctive names. It so happens that the muscles of cold blooded animals, such as the frog or newt, retain, for a considerable time after the death of the animal, their power of contracting on being stimulated, and thus we have been able to study the phenomena of muscular contraction to an extent which would have been impossible in a warm blooded creature, such as a rabbit; but we have every reason to infer from all that has been observed in the rabbit's muscles, that what I shall tell you of the changes occurring in the muscles of the frog may be held as being true also regarding the muscles of the rabbit, and indeed of man.

11. This gives me the opportunity of pointing out that what a physiologist terms *life,* is often different from what is understood by other people. There is still a lingering notion that life is some kind of subtile essence permeating the body, and capable of existing independently of it. Let us look at the question as physiologists. Here we have a muscle of a frog. You see it is contracting, in obedience to an electrical stimulation, just as it did in the body of the intact animal, before the frog was suddenly killed. The frog is dead, as a frog, but the muscle is alive. The frog has no feeling now, because its brain and nervous system is dead, but its muscle is still alive. Then, you say, has the muscle no feeling? I answer, none; it has no apparatus suitable for feeling; it has no brain or complex nervous organs; it has only a nerve or nerves, which excite the muscular structure to contraction. The nerve does not supply the energy; it only supplies the stimulus. But how, then, you ask me, is the muscle to be regarded as still

living? We say it is alive because it manifests a property which cannot be explained at present by any known physical or chemical laws—namely, that of contracting when I stimulate either it or the nerve going to it. *This irritability is one of the phenomena of life,* only met with in living things. The life we now study is the life of the muscle. Considerations of this kind have led physiologists to a great generalisation—namely, *that the life of the organism is the sum of the lives of its parts.* Each organ has, in a sense, its life; if we supply it with blood containing oxygen and nutrient matters, and thus keep up *repair,* and at the same time have arrangements for the removal of *waste,* we might keep the organ for an indefinite time alive. Here is the heart of a frog beating and doing work by lifting a little column of mercury; it is alive, but has no feeling; cut off from all central nervous organs, it *can* have no feeling; but still, it is a little living machine contracting in the same way, though not to the same degree, as it did in the living frog. Once its life, like the life of the muscle, was part of the life of the frog. The frog is dead, but the heart lives and the muscle lives; and if we could in like manner supply a brain with blood, and remove waste, it would also live. That is, it could think and remember, but it could receive no outside impressions, as it would be cut off from the mechanism of the senses. Could the brain of a higher creature be thus isolated, there might be, in such circumstances, the consciousness of existence, even a sense of individuality, but with no immediate knowledge of an outside world and only the existence of a dream.

12. But this is not all. Each organ consists of still smaller living parts, and could each of these be isolated, it would be found to have, in a sense, an independent existence. These parts are microscopical in size; and thus we come to the conclusion that *the life of the organism is the sum of the lives of microscopical portions of it.* A living body is an association of minute units, each of which has a life of its own, and the life of the body is

the collective life of these units. These minute parts have been called *cells.* This conception of the structure of the body has exercised a profound influence not only on physiology, but upon pathology, or the department of science treating of the changes in structure or function that produce disease. Just as healthy action is recognised as dependent on the life and activities of cells, so, in like manner, diseased action is dependent on changes occurring in these cells. The human body consists of a mass of cells, or of tissues formed from cells, and the life of the body is the aggregate of the lives of the cells.

13. But let us return from this digression to the changes happening in a muscle. If a living muscle, removed from a recently killed animal, be subjected to great pressure, it is found to contain a semi-fluid matter which can be squeezed out. This matter soon coagulates—that is, it forms a clot and a fluid. The clot is called *myosin,* and belongs to the group of bodies called albuminous, the type of which is white of egg. The fluid contains some soluble albuminous matter, some gelatine, some fatty matter, and a number of bodies which can be extracted or separated from it by water or alcohol. These latter bodies are hence called *extractives,* and consist of—(1) certain complex organic substances, such as creatin, xanthin, hypoxanthin, which are supposed to be waste products of muscle; (2) sugar; (3) a starchy like matter called glycogen; and (4) a kind of acid somewhat like the acid forming in sour milk, called lactic (*lac* milk), and hence termed sarco-lactic acid when found in muscle (*sarkos,* flesh, and *lac,* milk). In addition, muscle contains salts chiefly those of potash, about 80 per cent of the ash consisting of salts of potash. This is the chemical composition of an inactive muscle; but, when a muscle works, various chemical changes occur. In the first place, it becomes more highly acid. A living muscle at rest is neutral to test paper or faintly alkaline; but, after it has been caused to contract repeatedly, it becomes acid from the development of a larger quantity of the sarco-lactic

acid to which I have just referred. At the same time, carbonic acid is formed. Arterial blood passing through a muscle becomes venous, that is to say, the muscle takes up oxygen and gives out carbonic acid. A bit of living muscle always breathes, but it breathes faster during contraction than during rest. If we put a frog's muscle into an atmosphere containing oxygen, oxygen is steadily used up and carbonic acid formed. When, however, we make the muscle work in such an atmosphere, more carbonic acid is formed, but there is not a corresponding increase in the amount of oxygen used up. A muscle gives up no oxygen to the air pump (that is, it does not contain free oxygen), and it will contract in an atmosphere containing no oxygen, still even in these circumstances producing carbonic acid. It is clear, therefore, that oxygen does not necessarily unite with the carbon of the muscle at the time of contraction to produce carbonic acid, and the energy of the contracting muscle cannot come from the direct oxidation of any carbon compounds in it. The inference must be that the carbonic acid and sarco-lactic acid formed are produced by the splitting up of more complex organic substances, and that the muscle does not simply burn or oxidize the carbon supplied to it.

14. Helmholtz showed long ago that by continued contraction the substances in muscle which are soluble in water are diminished, whilst those soluble in alcohol are increased; or, in other words, some substances soluble in water are converted into other substances not soluble in water but soluble in alcohol. This again points to chemical changes happening in the muscle when it lives and does work. The living muscle substance, when it contracts, undergoes a certain amount of tear and wear; complex chemical matters in it split up and are reduced to simpler substances; and during rest, the muscle substance is again built up and restored. There is thus a constant series of chemical transformations; *waste* matters are formed such as sarco-lactic acid, carbonic acid, and nitrogenous substances, and *repair*, or the re-building of the living matter, occurs during rest. This short history of muscle gives us

a glimpse into the nature of the changes happening in all living matter. Whilst we cannot examine many of the tissues of the body so easily and successfully as we can examine muscle, we have every reason to believe that in these similar transformations occur. Vital activity of every kind is always accompanied by tear and wear, by waste and repair, by the splitting up of complex chemical substances into simpler ones, by chemical changes.

15. These chemical transformations, then, are the sources of the energy of the muscle. By these *heat* and *motion* are produced. When the muscle contracts, it becomes warmer, and it moves, and as you see, its movement can do mechanical work. This is true not merely of the muscles of the frame and limbs, but also of the muscular substance forming the heart, and found in the alimentary canal. Every beat of the heart involves waste and repair. The waste, no doubt, is only small in amount with each individual beat, and the repair is quick. Otherwise, the heart could not go on beating, without intermission, night and day, for fifty or sixty years, at the rate of say sixty beats every minute. It beats faster in youth than in middle life; and it usually becomes slower in old age. But the point I wish to impress upon you is that each beat means work done in driving the blood onwards, and consequently involves waste and repair.

16. Few have considered the work done by the heart. Let us try to form an estimate of it. We may measure force conveniently by what are called foot-pounds. One pound lifted one foot high against the force of gravity is a foot-pound. When one pound is raised six feet, one foot-pound of work is done for each foot of the height, so that the total is six foot-pounds. One hundred foot-pounds mean one hundred pounds lifted one foot high, or one pound lifted a hundred feet high. We can always readily express the work done by multiplying the load by the lift. Applying this method to the heart, we find that each stroke of the left ventricle, which sends blood throughout the body, ejects 6 ounces of blood. This it throws into the aorta, already full of blood, and against a pressure equal to that of the weight of ten inches of mercury. This column of mercury represents a column of blood about six feet in height. That is to say, the resistance offered to the ejection of the six ounces of blood is the same as the downward pressure of a column of blood six feet in height. The action of the ventricle overcomes this pressure, and thus each beat of the left ventricle exerts a force equal to that required to lift six ounces of blood six feet high. Six ounces is $\frac{3}{8}$ths of a pound avoirdupois; multiply $\frac{3}{8}$ths by 6 feet ($\frac{3}{8} \times \frac{6}{1} = \frac{18}{8} = 2\frac{1}{4}$) and we have $2\frac{1}{4}$ foot-pounds for each beat. Suppose the heart to be beating 70 times per minute, we have $157\frac{1}{2}$ foot-pounds per minute as the work done; 9,450 foot-pounds per hour, or 226,800 foot-pounds per day—that is, the work done by the left ventricle alone in 24 hours would lift 226,800 pounds 1 foot high, or it would lift one pound 226,800 feet high. Let us say that the right ventricle, as it has to propel the blood only through the lungs, does only about one third of the work of the left ventricle, then we have, putting it roughly, about 300,000 foot-pounds as the work of the heart. If the man weighed, say 150 pounds (nearly 11 stone),—an average weight,—the force thus exerted would lift the total weight of his body at least 2,000 feet high. I believe I have now given an estimate considerably under the mark in many instances; but it is sufficient to show the wonderful expenditure of energy continually going on.

17. But the work done by the heart is only a portion of the mechanical work done by the body. In addition, we have the movements of respiration occurring 14 or 15 times every minute, the mechanical movements of the limbs in moving the body and in doing an ordinary day's work of mechanical labour, and many other slighter movements, such as that of the food along the bowel, &c. Further, we have the loss of energy in the form of *heat*, which is constantly being produced in the body by the chemical changes I have mentioned. This heat warms the blood and the tissues, and is distributed by the blood, as by a system of hot water pipes in a building, throughout the body. Part of this

heat is lost by warming the food and drink we consume and the air we breathe, but the most of it escapes from the surface of the body, heating the air and adjacent objects. The use of warm clothing and of blankets is to prevent the loss of this heat. These give no heat to the body; they only diminish loss, as they are bad conductors of heat, and the heat consequently will not pass through them.

18. I have calculated the total amount of energy expended as mechanical work by a labouring man, and it comes to about 900,000 foot-pounds; if we add to this the work done by the heart, by respiration, and by the internal mechanisms of the body; further, if we add to this the mechanical equivalent of the heat produced in the body; the sum expressing the total energy expended during 24 hours comes to the enormous amount of about six million (6,000,000) foot-pounds, a force sufficient to lift his body, suppose it weighed 150 pounds, 40,000 feet, or nearly 8 miles high. It can also be shown that, considered as a mere machine for the production of work, more effective work, as mechanical movement, can be got from the body than from any machine yet contrived by man. I am told that the best constructed steam engine will yield only $\frac{1}{8}$th, as effective mechanical work, of the energy supplied to it, whereas the living body will give back between $\frac{1}{4}$th and $\frac{1}{5}$th of the total energy conveyed to it by the food and the air. Again, in the engine, the remaining $\frac{7}{8}$ths are expended in heat which is of no service, and is actually lost; but in the living body the heat, whilst no doubt it is ultimately lost, supplies one of the most important conditions of life, and renders vital action possible.

19. This gives one some idea of the enormous amount of energy produced each day in the body of an active living man. I have already shown that this energy comes from the union ultimately of the oxygen of the air and the organic substances in the food. This leads us to the practical question of striking a balance between the input and the output of matter, the input and output of energy, or in other words, the balance between Waste and Repair, as is attempted in Tables I and II.

TABLE I.

Attempt to calculate the *Income* and *Expenditure* of MATTER during twenty-four hours of a man of average size and weight, and in a state of health. (In Troy weight—480 grains to 1 ounce, and 12 ounces to 1 pound.)

INCOME.	lbs.	oz.	grs.
Oxygen taken in by lungs in respiration,	1	11	0
Food—			
Albuminous matter,	0	4	0
Fat,	0	3	0
Starch or sugar (carbohydrates),	0	10	0
Salts,	0	1	0
Water,	7	4	0
	10	9	0

EXPENDITURE.	lbs.	oz.	grs.
Lungs—			
Water,	0	10	6
Carbonic Acid,	2	0	0
Skin—			
Water in sweat,	1	8	0
Vapour,	0	3	2
Carbonic acid,	0	0	60
Salts, too small to be stated.			
Nitrogenous matter, too small to be stated.			
Kidneys—			
Water,	4	0	0
Urea,	0	1	20
Uric acid,	0	0	7
Hippuric acid,	0	0	6
Creatin, &c.,	0	0	13
Pigment,	0	0	150
Sulphuric acid,	0	0	30
Phosphoric acid,	0	0	45
Chlorine,	0	0	105
Ammonia,	0	0	10
Potassium,	0	0	30
Sodium,	0	0	165
Calcium,	0	0	3
Magnesium,	0	0	3
Bowels and Liver—			
Water,	0	4	0
Salts,	0	0	90
Nitrogenous matter and refuse,	0	1	90
	9	4	345
Organism has gained,	1	4	135
	10	9	0

The foregoing figures are only approximative; but they have been compiled from the most trustworthy sources of information. The gain is undoubtedly too great, as shown by this balance sheet, and must not be taken as representing a real case; but the figures generally are pretty near the mark.

20. Without troubling you with the exact figures, I may say that a healthy adult man introduces into his body during twenty-four hours, about 11 lbs. Troy weight of matter. These 11 lbs. are made up of nearly 2 lbs. of oxygen taken into the blood in the lungs by respiration, nearly 2 lbs. in the form of food, and about 7 lbs. of water. During the same period, he will lose 10 ounces of water and 2 lbs. of carbonic acid by the lungs, nearly 2 lbs. of matter, chiefly water, by the skin, about 4½ lbs. of water, nitrogenous matter, and salts by the kidneys, and about 6 or 8 ounces by the bowels. These figures are, of course, subject to great variations, and they have no intrinsic value; they are only approximations, but they bring out this astonishing fact, that a man may exchange with the outer world matter equal to his own weight in about fourteen days. Now, don't mistake me. I do not mean that the whole matter of the man's body is changed in fourteen days. There is no reason to suppose that this is the case, but the contrary. Certain tissues, such as the blood itself, the muscles, the nervous system, the glands, undergo rapid changes, whilst others, such as the bones and gristles and fat are more permanent, and the matter forming these may exist in the body for a long time. What I do mean is, that matter equal to the weight of his own body may be exchanged between the man and the outer world in fourteen days. When we consider the millions of living forms on the earth's surface, we see at once that a not inconsiderable portion of the movable matter is constantly circulating between the dead and the living state. There is a circulation of matter between organized and unorganized nature. The matter now in our bodies may have once formed the bodies of other animals, and may be destined to pass through many forms in the future.

21. This view of the subject also suggests the thought that life

is not a property associated with any particular mass of matter. Matter passes from the dead into the living condition, and from the living condition back again into the dead state. At one time the materials forming a piece of bread were in a sense alive in the tissues of the plant, and they will live again when they become part of our bodies. The matter of the muscle of the ox we eat was once dead in the soil or floated in the air, then it became grass, then muscle living and working; then it dies again, and again we convert it into living matter, when it becomes part of ourselves. And when we die, the matter of our dead bodies may spring into new life in the bodies of plants and animals. Ceaseless change, ceaseless change is the order of nature!

22. Just as I have shown you there is waste and repair of matter going on in the body, so there is expenditure and renewal of *energy*. I have made a statement as to the expenditure of energy, how is this enormous expenditure met? We say, of course, from the food, but let us see that we understand the rationale of the process.

TABLE II.

Attempt to show theoretically the *Income* and *Expenditure* of ENERGY, during twenty-four hours, of a man of average size and weight in a state of health. In Foot-pounds.

INCOME.

	Foot-pounds.
1500 grains of albuminous matter completely oxidized will yield	1,110,000
1500 grains of fat, do. do.	2,304,600
3600 grains of starch, as in rice, &c., do. do.	2,386,080
Foot-pounds,	5,800,680

EXPENDITURE.

	Foot-pounds.
Energy of heart,	362,880
,, respiration,	84,000
,, eight hours' work,	900,000
,, heat during twenty-four hours,	4,453,800
Foot-pounds,	5,800,680

23. Chemists are able to tell us, by refined methods of experi-

ment, how much energy in the form of heat can be got from the combustion of any given amount of matter used as food. Suppose we take an ounce of starch, which is a substance composed of carbon, hydrogen, and oxygen, we can ascertain how much heat would be given out if it were completely burnt, that is, if all the carbon in it were converted into carbonic acid, and all the hydrogen in it into water by union with the oxygen of the air. Now this heat might be employed to do mechanical work. For instance, we might burn starch in the furnace to heat the boiler of a steam engine—a most irrational and expensive proceeding certainly, but it might be done. If we expressed all the energy of the heat as mechanical work in foot-pounds, we are told that the complete oxidation of a little less than a quarter of a pound of albuminous food, such as we have in lean meat, less than a quarter of a pound of fat, and more than half a pound of starchy food, such as we have in rice or flour (that is, about one pound of solid matter altogether), would be sufficient to supply all the energy expended by a hard working man, amounting, as I stated already, to about 6,000,000 foot-pounds. But if you refer to this table (see Table V), you will see that, to form a healthy diet, a man requires much more than a pound of solid matter. He will require nearly two pounds; and the discrepancy between the theoretical calculation and the actual facts may be explained thus:—that no food is completely oxidized in passing through the body. The arrangements of the body do not permit of complete oxidation. There is always a surplusage of matter introduced, and the whole of it is not got rid of in the simplest form. If it were, we would give off from the body only such simple compounds as carbonic acid, water, and ammonia; but we throw off many more complex substances, which might be further oxidized, and thus caused to produce more energy. Still, I think it is remarkable that the processes and calculations of science should coincide, even to such an extent, with the teachings of experience. (For a statement of these results see Table III.)

Table III.

Giving in foot-pounds the Energy produced by the complete oxidation of

	Foot-pounds.
1 oz. Troy of beef-fat,	691,380
,, butter,	553,860
,, arrowroot (starchy food),	298,260
,, lean beef,	388,980

From what might be called an ordinary diet, the following energy might be got :—

	Foot-pounds.
1500 grains of albuminous food,	1,110,000
1500 grains of fat,	2,304,600
3600 grains of starch,	2,386,080
Foot-pounds,	5,800,680

24. I have shown you that there is a circulation of matter going on between the living and the dead world. So, in like manner, there is a circulation of energy. The energy of the sun's rays enables the plant to store up matter in the form of starch and sugar and albuminous matter ; in these compounds energy is, as it were, locked up ; by and bye these become part of an animal and the starch and sugar are oxidized, and the energy is again given out in the form of heat and motion. Thus we may trace back all the energies of our existence to the rays of the sun, and it has often seemed to me not at all strange that men should be found, like the Parsees of India, worshipping the sun as the giver of life and the source of temporal blessings.

25. Let us now apply the principles laid down to the practical result of framing a proper diet for a healthy man. Under the name *Food* we include those substances, either in the solid or the fluid form, which are required for the nutrition of the body. When the body is analyzed by the chemist, it is found to consist of certain substances called *proximate principles*, of complex chemical composition, and when the different kinds of food are analyzed they are found to contain usually the same kind of proximate constituents as are met with in the body. Such proximate principles are water, salts, albuminous matter, fats, and starches and sugars. It is rare that food, in the common sense of articles of diet, consists of one proximate principle only. An article of diet usually contains several principles. Thus, water holds various salts in solution, butcher meat contains albuminoids, fats, salts, and water; and milk, which may be regarded as a typical form of food, inasmuch as it is sufficient for the nutrition of the young of all animals that suckle their young, contains, in due proportion, all the proximate principles. This will be seen on consulting the following Table :—

TABLE IV.

Showing the composition, in one hundred parts, of various articles of food.

Nature of Food.	Water.	Albumen.	Starch.	Sugar.	Fat.	Salts.
Bread, . . .	37	8·1	47·4	3·6	1·6	2·3
Wheat Flour, .	15	10·8	66·3	4·2	2·0	1·7
Oatmeal, . .	15	12·6	58·4	5·4	5·6	3·0
Rice, . . .	13	6·3	79·1	0·4	0·7	0·5
Potatoes, . .	75	2·1	18·8	3·2	0·2	0·7
Peas, . . .	15	23·0	55·4	2·0	2·1	2·5
Milk, . . .	86	4·1	...	5·2	3·9	0·8
Cheese, . . .	36·6	33·5	...	...	24·3	5·4
Beef, . . .	5·1	14·8	...	...	29·8	4·4
Pork, . . .	39	9·8	...	...	48·9	2·3
Poultry, . .	74	21·0	...	...	3·8	1·2
White Fish, .	78	18·1	...	...	2·9	1·0
Eggs, . . .	74	14·0	...	...	10·5	1·5

26. With the aid of this table, contrast the composition of bread with rice, bread with potatoes, bread with cheese, bread with beef, potatoes with beef, and potatoes with cheese, so as to see how one article of food may act as the complement of the other in forming a dietary. You will observe that rice and potatoes are rich in starch but poor in albumen, and that consequently they may be combined advantageously with beef, pork, poultry, fish, or cheese, where the reverse is the case. Again, note the composition of milk and of egg, both of which may be regarded as typical foods, as they are both primarily intended for the nourishment of the young animal.

27. From what I have said in this lecture, it will be evident that the amount of food must have some direct relation to the work done by the individual. Hard work means expenditure of matter and energy, and these must be supplied by food. This table shows the amount in ounces avoirdupois of the different materials of dry food required under different circumstances :—

TABLE V.

Showing the amount of *Diet* in ounces avoirdupois.

Nature of the Diet.	Nitrogenous or Albuminous matter.	Fat.	Starch or Sugar called carbo-hydrates.	Salts.	Total.
Bare subsistence diet,	2·33	0·84	11·69	...	14·86
Adult in full health with moderate exercise,	4·215	1·397	18·960	0·714	25·286
Active artisan, not overworked,	5·41	2·41	17·92	0·68	26·42
Hard working labourer doing heavy work,	5·64	2·34	20·41	0·68	29·07

Add to each of these from 60 to 80 ounces of water, taken either alone or as part of the food in a succulent or cooked form. Thus, it appears that in ordinary life, and with a fair amount of labour to perform, a healthy adult requires daily about 28 or 30 ounces of dry nutritious food, along with about 70 ounces of water.

28. A healthy diet must fulfil the following conditions :—

1st. It must contain a due proportion of the various proximate principles found in the body of man.

2nd. It must have a certain sapidity or flavour which will render it palatable, and thus indirectly promote the efficiency of the digestive process. Here good cookery is of advantage.

3rd. It must be adapted, as regards quantity and quality, to the amount of work done by the individual.

4th. It must be adapted as regards quality to the climate. In cold climates fat can be freely used, whereas in hot climates the starchy and sugary foods are the most healthful.

29. Each proximate constituent of food has its own part to play in the economy of the body, and although the exact function of each has not been thoroughly worked out, the following statements may be accepted as being generally correct.

30. *Nitrogenous food*, such as albumen, white of egg, lean meat, the gluten of flour. The effect of a nitrogenous diet seems to be to increase largely the changes in the nitrogenous tissues of the body. With a meat diet the consumption of oxygen is largely increased; or in other words, the oxidizing activity of the body is increased by a meat diet. A meat diet largely increases the number of red blood corpuscles, and so increases the amount of oxygen with which the tissues are supplied, these corpuscles being the carriers of oxygen from the lungs to the ultimate tissues of the body. Food of this kind probably contributes to the building up of the frame, but it is not a large contributor of energy.

31. *Fats*, as met with in the fat of butcher meat, oils, butter, &c., *and carbo-hydrate food*, such as starch and sugar, containing no nitrogen, and existing in sago, rice, tapioca, flour, oatmeal, biscuit, bread, &c. A non-nitrogenous diet alone is soon followed by death. The food is not digested and starvation ensues. When a small amount of fat is taken, along with a moderate quantity of albuminous food, the whole of the carbon of the food re-appears in the excretions. No fat is stored up. But if we increase the amount of fat, a point is reached at which the excess of carbon is retained in the body to form fat. The same is true regarding starch and sugar. When the amount is small, no additional fat is formed; but if it be increased beyond a certain limit, carbon is then stored up as fat. Fats, starches, and sugars differ therefore from albuminous foods in not exciting increased tissue change. In a pig fattened by Messrs. Lawes & Gilbert, 472 parts of fat were

stored up for every 100 parts of fat in the food, and no less than 21 per cent of the dry nitrogenous food supplied to this creature was retained in the body as fat. Thus, fat may be formed in the body out of something which is not fat.

32. The presence of fats or starches in food check changes in nitrogenous tissues. But if we take a fixed amount of fat or starchy matter in food, any increase in the albuminous matter seems to increase the consumption of carbon. Thus albuminous food increases the changes not only in nitrogenous but also in non-nitrogenous tissues. A diet of lean meat, without sugar or starches, increases the changes in fatty tissues and leads to the consumption of fat. This is the explanation of the system of Mr. Banting, often successful in reducing obesity in excessive fatness. The lean meat increases the oxidations in the body and excites chemical changes in the fatty tissues, and thus the fat rapidly disappears. It would appear that both an albuminous diet and a diet rich in carbo-hydrates may make a man fat.

33. It is not easy to explain the nutritive difference between starches and sugars. In the final combustion of the two, while starches and sugars require sufficient oxygen only to combine with their carbon, there being already sufficient in the starch or sugar itself to form water with the hydrogen present; fats require in addition oxygen to burn off some of their hydrogen. Thus, the combustion of fats will produce more heat, and this may explain why they are so useful in very cold climates. Starches and sugars are more digestible than fats; but, on the other hand, fats, when oxidized, yield more energy in a given weight. As to any difference between the nutritive properties of starch and sugar, we know little; but, in experiments on animals, it has been found that cane sugar is more fattening than starch.

34. *Gelatine Foods.*—These will not take the place of albuminous foods, and animals will die if fed on gelatine just as when fed on a non-nitrogenous diet. It is quite probable, however, that gelatine may also assist in the formation of fat. Gelatine, as in

jellies often given to invalids, is not nutritious : to make jellies so we must combine them with bread or the juice of meat.

35. *Salts.*—These do not undergo much chemical change in the body, and therefore yield little or no energy, and still they are absolutely necessary or highly beneficial. They seem to have some influence in directing the chemical operations happening in the tissues. We find sodium and its salts, more especially chloride of sodium or common salt, in the fluid of the blood, whilst potassium and phosphates exist in the solid red corpuscles. Again, phosphorous seems to be absolutely essential to life, as much so as carbon or nitrogen. Sulphur enters into the composition of various albuminous compounds. We know nothing of the uses of salts, but experience shows that they are needed. Excess of common salt and absence of fresh vegetables will soon produce scurvy and a weakened state of body. Common salt should be freely used in almost all articles of diet. It is found in almost every tissue ; and, although we do not know what it does, there can be no doubt it has an important part to play. Salts of lime, as in good bread and oatmeal, are required, especially in early life, for the growth of bone.

36. As regards the *energy* producing properties of the different proximate principles of food, I may briefly state that carbo-hydrates —that is, starches and sugar—and also fats, apparently yield energy to a greater extent than purely nitrogenous or albuminous food. When a man undergoes severe muscular exercise, there is not tear and wear of nitrogenous matter to any great extent, but there is a remarkable increase in the amount of carbonic acid exhaled, showing that changes in carbo-hydrates are the chief sources of the energy. A meat diet may be suitable for sudden and violent exertion continued for a short time, probably on account of its stimulating properties, but a diet rich in starchy matter and sugar, with a small amount of nitrogenous matter, in fact, such a diet as we have in oatmeal and milk, or milk and bread, is the most suitable for the sustained exertion of ordinary work.

37. I have now shown you that *waste* happens in every tissue of the body during its vital activity. *Repair* is therefore necessary. How is repair accomplished? By two channels. First, food is digested, made soluble, absorbed, and converted into the elements of blood. This blood is carried by the circulation near to each living tissue of the body. By the arteries it is carried to the capillaries, minute vessels of microscopical size, which form networks of almost inconceivably fine meshes in most of the tissues, the networks being finest in those tissues which perform very active functions. In the little areas surrounded by these networks, the living tissues are found; and from the blood thus supplied they obtain nutritious matters. The living matter really lives upon these matters, taking them into its own substance, and by a chemistry too subtle at present to be followed, converts them often into new materials. Thus is nutrition accomplished. But every tissue breathes. I have shown you that a muscle breathes, and that it breathes faster when working than when at rest. How does the oxygen reach the tissues? This is done by the agency of the red blood corpuscles.

38. If we examine a drop of blood under the microscope, we find it consists of a fluid in which float two kinds of corpuscles, the *red* and the *white*. The red are little biconcave discs, about the $\frac{1}{3500}$th of an inch in diameter; the white are little lumps of living matter, having a granular appearance, and somewhat larger than the red ones. About one white corpuscle may, in healthy blood, be found for 400 or 500 red ones. The red corpuscles exist in enormous numbers. The amount of blood in the body is about $\frac{1}{13}$th part of the body weight, and it has been calculated that, if the red corpuscles were placed in a single layer side by side, like coins on a board, they would cover an area of about 3,000 square yards. Physiologists have been able to analyze these corpuscles, and, by the aid of the spectroscope, to get an insight into their work in respiration. We find that the colouring matter of the corpuscle, called *hæmoglobin*, has a wonderful

affinity for oxygen, and that it gives it up to the tissues under special physical conditions.

39. This colouring matter of the red corpuscles, whilst these are in the lungs, takes up oxygen gas, each corpuscle taking up its own appropriate quantity; the corpuscles are carried by the heart through the circulation; and in the smallest vessels, at the place where the blood is brought near the living tissues, the colouring matter gives up its oxygen to the tissues, and goes back to the lungs for more. This colouring matter is therefore the carrier of oxygen from the lungs to the tissues. Each tissue breathes in the fluid surrounding it, just as if it were an aquatic organism. It receives oxygen and gives up carbonic acid, and the blood is therefore not merely the *nutritive* but the *respiratory* medium in which the tissues live.

40. But if waste occurs in the tissues, the waste products must be removed, otherwise they might act injuriously. This is accomplished by a special set of vessels called *lymphatics*, found in almost every tissue, which act as drainage tubes, carrying away the excess of nutrient matter that has transuded from the vessels, and also the waste products formed by the decomposition of tissue. But, in a well ordered manufactory, waste products are not thrown aside as useless. Each product is economically used up; and thus the manufacturer saves money and benefits mankind. So in the human body the waste products are not at once thrown aside as useless, but they are carried by the lymphatics, after changes undergone in a special system of glands, back again into the blood, so as to be at least partially used up again. Thus, in the economy of the body there is a kind of parsimony, an indication of saving, a physiological protest against waste and extravagance which carries with it its own moral.

41. I have in this lecture tried to carry you into some of the secrets of the living organism. We have seen that waste is a necessity of living action; that this waste consists in the expenditure both of matter and of energy; and that repair is

accomplished by supplies of food and of oxygen. I have also tried to lay before you some of the principles which should guide us in our selection of food, most of which coincide with experience. I fancy I hear some of you say, Why trouble about the science of the matter, seeing experience has guided us so far on the right road? Why bother about matter and energy when we find after all that the conclusions of scientific men are in favour of oatmeal porridge and milk, or a beef steak and potatoes? The answer is, that even supposing we do live in accordance with the laws of health, as regards food and work, which is not the case in many instances, the mind craves for information, and refuses to be satisfied with mere sustenance. Man will not live on bread alone; he desires knowledge and a further explanation of the why and how of things; and such knowledge will slowly influence his whole life and character. It may not do so in a generation; it may need many generations before the influence of the knowledge may become habitual; but the effect of all advances in true knowledge must lead to a nobler standard of life, both as regards the individual and as regards the race.