

Address

ON

APPLIANCES USED IN BIOLOGICAL INVESTIGATION.

Delivered at the opening of the Biological Conferences in connexion with the Loan Exhibition of Scientific Instruments, South Kensington.

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CHAIRMAN.

IT having been made part of the duty of the chairman of each section of this exhibition to deliver an opening address, it became necessary for me to select a subject. I have had little difficulty in doing this. I propose to attempt to give you an account of some of the instruments of research which you have already seen in the adjoining room, selecting for description and illustration those which are of the simplest construction, and at the same time serve to exemplify the most important and generally employed methods of investigation. In attempting to carry out this intention my scope will be far from ambitious. In addressing you I will take it for granted, for the moment, that none of the distinguished physiologists whom I see before me are present, and will make it my aim to explain to those who have no special knowledge of that branch of natural science which deals with the phenomena of the life of plants and animals, and which we therefore call biology, some of the appliances which are of the greatest value in the study of those phenomena.

You are aware that the Committee, in order to render these conferences as useful as possible, have thought it desirable that we should devote our attention chiefly to those subjects of which the instruments contributed afford the fullest illustrations. These subjects are: first, the methods of measuring and registering the movements and other vital phenomena of plants and animals; secondly, the methods of investigating the eye as an optical instrument; and, thirdly, the methods of preparing the tissues of plants and animals for microscopical examination.

Of these several subjects it is proposed that we should concern ourselves to-day chiefly with the first. I shall, therefore, occupy your attention with an account of some of the simplest methods of physiological measurement, and particularly of the methods of measuring the time occupied in the phenomena of life, in the hope that what I tell you may serve as an introduction to the more complicated descriptions which will be given by Professor Donders, M. Marey, and other eminent men, of the elaborate and beautiful instruments which they have contributed to the collection.

I will commence by making the statement, which may perhaps seem to some persons strange, that the study of plant and animal life is entirely an affair of measurement. I will endeavour to offer to you grounds for thinking that it is so, and must be so.

To begin with, it is the character of the scientific study of nature, as contrasted with that vague contemplation of natural objects which many persons imagine to be the business of the naturalist, that it consists in bringing the unknown into relation with the known. Whatever may be the object of our study, whether it be a country, a race, a language, a plant, or an animal, the process by which we come to know it is throughout a process of comparison—a process in which we compare the object of study in respect of such of its features as interest us, with some known standard. And the completeness of our knowledge is to be judged of, first, by the certainty of the standard which has been assumed by us to be true, and, secondly, by the accuracy of our method of comparison and the care used by us in applying it.

Now “comparison with a standard” is only another expression for “measurement”; and in biological research, I

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repeat, accurate comparison with standards is quite as essential to the value of results as it is in physics or chemistry. Those who have attended the conferences relating to these subjects have learnt how much of the work of the physical investigator is of this nature. From his, our work differs only in this respect, that we do not, as he does, seek out and determine the value of our own standards, but accept as such those well-ascertained certainties of nature which he has already measured out for us. In many cases we do not even concern ourselves in knowing how our standards are obtained, being content to know that they have received the stamp of acceptance in the more exact sciences on which we are constantly dependent for guidance.

I will now endeavour to illustrate my proposition by examples:—

The first objects which strike the eye on entering the room are the large collection of microscopes. You will say, Surely the microscope cannot be regarded as an instrument of measurement. I answer, In so far as it is an instrument of research, and not a mere pastime, it is so. All real microscopical work is matter of measurement. Let us take as an example one of the simplest and best known of microscopical objects—a coloured blood-disc. What I see is a mere circular outline. But I know that that outline represents a lenticular disc of transparent elastic material. All that these words convey has been learnt by methods of measurement. Proceeding from its form to its attributes, I can, by a still more direct application of the method, determine from the microscopical examination of the smallest quantity of blood, even of a drop, the proportion of blood-corpuscles, and consequently, by approximation, the percentage of hæmoglobin and of iron which it contains. As this is a recently discovered method, and one which possesses great practical value in its applicability to medicine, and can be illustrated by showing you the instruments, I will refer to it as my first example. I think I may take it for granted that everyone present is aware that blood is a fluid mass in which solid particles—the corpuscles already mentioned—are suspended. These corpuscles exist in such enormous numbers that in a cubic millimeter (i.e., in the bulk of a pin-head) there are about five millions of them. Even those who are not physiologists will readily understand that it is a matter of the greatest importance to determine in what proportion these little particles exist in human blood at any given time. It is of importance not merely to the physiologist, who knows that the corpuscles are the agents by which oxygen is conveyed from the external air to the living protoplasm out of which our tissues are built up, but still more to the pathologist, who, in a number of cases, recognises in the destruction of these coloured discs one of the most serious results to ordinary health. How can it be known, in any individual case, whether the number of coloured discs circulating in the blood-stream is below or above the normal standard? The essence of the method consists in mixing a measured (but very minute) quantity of blood to be investigated with a much larger quantity (250 times its bulk) of another liquid which is without action on the blood-corpuscles, and introducing a layer of the mixture between two horizontal and parallel plates of glass which are at a measured distance from each other. If now a cube, measuring a fifth of a millimeter, is, so to speak, cut out of the stratum, it is evident that it will correspond to about a thirty-thousandth of a cubic millimeter. Consequently, if a census is taken of the number of corpuscles such a cube contains, it would amount to 166. Now, though, at first sight, it might seem impossible to make such an enumeration, it can in practice be carried out with more than sufficient accuracy, especially if the mean result of several countings is taken.

Let me now leave the microscopes and microscopical apparatus, of which the excellences will be fully explained to you by others, and draw your attention to other instruments. You will find, if you look through the room or through the catalogue, that they are all more or less instruments of measurement. Thus, we have instruments for determining the weight or bulk of the animal body or of its parts, others for measuring growth—particularly the growth of plants, others for measuring the various results of muscular action, and others for investigating the electrical phenomena of plant and animal life.

Numerous as are the forms of apparatus of which we have here examples, they are but few as compared with the

number which must be actually used by the biologist, for those only are here represented which are specially biological. For many purposes the biologist has recourse to the methods, and consequently to the tools, which are to be found ready to his hand in the physical and chemical laboratory. We use, for example, the balances, the galvanometers, the polariscopes, with which the physicist provides us, and do not call them biological instruments, although we biologists are constantly using them. The only instruments which we can thus designate are those which have been either entirely devised for physiological purposes, or have been so modified for such purposes as to be in some sort new instruments. I would take, as an instance of this, the kymograph of Prof. Fick. It is essentially a Bourdon's manometer, to which such a form has been given as to adapt it, not for its more usual purpose—that of a steam-gauge—but for the measurement and registration of the fine variations of the pressure of the blood against the internal surface of the arteries. Many other examples might be given of the same kind, so that if we were to transfer from the biological department every instrument in respect of which it could be shown that it was identical in principle with some instrument ordinarily employed in physical research, we should have very little indeed to show you.

Even if it were possible within the limits of a short address to give you an account of the various instruments of measurement contained in the collection, it would be far from desirable; for many of them will be explained to you, as I have already said, by those to whose ingenuity and scientific knowledge they owe their existence. I shall therefore confine myself to the description of one or two familiar and well-known methods, which I shall select rather because they can be easily explained, and because they admit of some degree of experimental illustration; and with this view will endeavour to exhibit to you their applicability to phenomena which relate to the human body, and not merely to those observed in plants or animals. There are two sorts of measurement so applicable, and which I can readily exemplify—namely, measurement of time and measurement of volume, or rather of changes of volume, both of which yield results of importance and interest.

The simplest of all cases of nervous action is that in which a muscle is thrown into contraction when influenced by a change having its seat in a distant part—i.e., in one of the central organs of the nervous system—in a motor centre, this motor centre being awakened to activity by an impression received by it from outside. This process, which is called reflex action, and has been recognised by physiologists, from a very early period, as a characteristic of animal life, may evidently, if we place before our minds what occurs in the centre itself, be described as consisting of three successive stages. Of these, the first is fitly designated that of excitation—wakening, and the third that of discharge; while, during the intervening period, the condition of the centre may be regarded as one of preparation for action, for, having been acted on by the stimulus, it is, as it were, preparing to discharge itself.

The point that I wish to be borne in mind is that each of these stages occupies time, and that in each instance this time admits of measurement, so that of a number of nervous processes, all of which appear to our unaided appreciation instantaneous—"as quick as thought"—some are found, when submitted to the test of measurement, to differ very remarkably from others. Thus, for example, if we confine our attention for the moment to the simplest reflexes, we shall find that, whereas the time occupied in the transmission of the wakening influence from the surface of the body to the centre is exceedingly short, and that occupied in its discharge from the centre to the muscle is also exceedingly short, that during which the centre is occupied, so to speak, in preparing itself for action is of relatively long duration, although to us it appears instantaneous.

The simplest measurement is that of the third stage in the process, that of the conveyance of the discharge from the centre to the muscle. This measurement may be accomplished with the greatest exactitude in the motor nerves of those animals in which the vital properties are retained for long after death, and particularly in those of the frog. You will find several forms of apparatus in the collection specially adapted for this purpose. As, however, I propose to-day to give instances in which the human body only is

used, I will not describe these instruments, all of which are included under the term "myograph."

In man the rate at which a message is transmitted along a nerve has been determined by Helmholtz as 110 feet per second. The way in which we can arrive at the result is easily explained. If you place the half-closed hand, with its ulnar side resting on the table, and the thumb supported on a horizontal lever above it, it is evident that if, by voluntary effort or otherwise, a contraction of the muscle is determined, by which the thumb is brought towards the index-finger, the moment at which that takes place will be indicated by the descent of the lever. Normally this contraction occurs only when it is determined by the will, or in consequence of the excitation of some subordinate motor centre; but I can counterfeit that action by exciting the nerve by which the muscle is supplied at some distant part of its course, electrically, the effect of which, so far as concerns the muscle, will be the same as if it contracted voluntarily. It happens that the nerve which supplies the adductor muscle of the thumb comes in its course very near to the surface—viz., at the elbow. I can, therefore, at any moment, by causing an induction shock to flash through the ulnar nerve at the elbow, produce the desired muscular action. The moment at which this occurs is not the moment at which the muscle contracts; it precedes it by an extremely short but yet measurable interval of time.

Let us, before proceeding farther, agree to call the first act, that by which the induction shock is sent through the muscles, the *signal*; the second—viz., the contraction of the muscle, the *event*. In the case before us the signal is given by the closing of a voltaic circuit. If the lever on which the thumb acts is so arranged that when pulled upon it breaks the same circuit, then we have the two acts of which the true difference is required indicated by the duration of the current, so that if that duration can be measured it gives us all that we want. Now there are two methods of measuring the duration of a voltaic current, both of which are very commonly employed in physiology. One may be called the graphical, the other the electrical. The principle of the graphical method is this:—Having a sheet of paper which moves horizontally at a uniform rate by clockwork (say one metre per second), if I can by any mechanism make a mark upon that paper at the moment at which the current begins, and another when it ends, I shall find that the two marks are separated from each other by a horizontal interval, the length of which corresponds to the duration of the current. Thus, if the current has lasted one-hundredth of a second, it is certain the interval will measure one-hundredth of a metre, or one centimetre. But the record will not be correct unless the mechanism employed be of such a nature that there is either absolutely no loss of time in making either mark, or the loss is exactly equal in the two cases. Now it is easy to secure these conditions. The simplest contrivances for the purpose are those in which both signal and event are indicated by the motions of a soft iron plate, which is supported by a spring over an electro-magnet in such a way that the spring and the magnet act upon it in opposite directions. Thus, in the apparatus on the table, which is much used for a variety of purposes connected with time-measurement, you have a good illustration of this principle. With its aid I shall be able to make an experiment so as to exemplify the method. You will see in a moment, from the diagram which exhibits the arrangement, that the *signal* by which the person experimented on is acted upon, and the *event*—i.e., the muscular movement which results—must coincide, the one with the opening, the other with the closing, of a voltaic circuit in which the electro-magnet is included. Consequently there must be mechanical or electrical arrangements of such a nature that on the one hand A can promptly give his signal and close the circuit by the same act, while B, on the other, can acknowledge the signal and open the circuit also by the same act.

Let us now proceed to the experiment. We will compare two kinds of signals—a sound signal, and one acting through the nerves of common sensation. For both purposes I will be myself the subject of experiment. The signal will be given from the other end of the table, in the one case by a bell which will be rung by the same current which marks the time on the recording cylinder; in the other, by an induction-shock, which I will receive on the tip of my tongue. In the two instances the process is similar but not identical.

In both the centre is the same, and the motor nerves by which it discharges itself are the same, but the afferent nerves, and particularly the terminal apparatus on which the signal directly acts, are different.

Let me now direct attention to the results. In either case the result is a horizontal straight line written on the cylinder, of which the end and beginning are indicated by the marks made by the lever. How do we translate this straight line into time? It must be done by comparison with an invariable standard. The time-value of the line depends on the rate of movement, and the only way by which we can determine this rate with accuracy is by comparison with an invariable standard. You have before you a tuning-fork which, as you hear, is kept in vibration by a powerful electro-magnet, to which it stands in the same relation as the hammer of an ordinary induction apparatus stands to its electro-magnet, interrupting the current in exactly the same way. The fork vibrates 250 times per second. Each vibration therefore lasts four-thousandths of a second. If, therefore, I allow the fork to trace its vibrations simultaneously on the cylinder, immediately below the line I want to measure, it is obvious that I shall be able, without the slightest difficulty, to determine the time occupied in drawing the line. Employing the apparatus you now see, I am able to measure with accuracy to one five-hundredth of a second.

Some one will now perhaps be disposed to ask—What is the use of all this? Want of time renders it impossible to answer this question fully. I must content myself with a single example. It is now well known that by exciting certain spots on the surface of the brain definite movements of the limbs of animals can be determined. Of these movements two explanations have been given. On the one hand, it is said that the effects are due to the excitation of the centres from which proceed the motor nerves from which the muscles thrown into action derive their supply; while, on the other, it is supposed that a complicated series of changes originate in the brain in consequence of the excitation—more or less analogous to a psychical process—of which the muscular contraction is the final event. Of these two alternatives we are able to exclude the first by time-measurement. If the process is one of excitation of the origins of motor nerves, the time occupied ought not to exceed, say, a fortieth of a second. The actual interval between excitation (signal) and the result (event), is ten times as long. We are therefore sure that we have not to do with a mere transmission of excitation along motor channels.

I have now, in conclusion, to speak of the other kind of measurement to which I previously referred, the measurement of changes of form of organs in relation to the time occupied.

For this purpose the biologist uses graphic apparatus of the most various kinds, of which you will have some beautiful examples brought before you to-day. For the most part these have for their purpose the transference of a rhythmical to-and-fro vital movement to a lever of some kind, the motions of which, by virtue of the mechanical arrangements by which it is brought into relation with the organ or limb, imitate its movements exactly. I cannot refer to better examples than those which are to be seen in the Donders and Marey collection. But it has always been recognised that it would be of great importance to obtain direct records of changes of volume of organs or organisms independently of changes of form. We have in the collection two instances in which methods for this purpose have been applied with great success.

In the apparatus devised by Professor Hering for recording the respiratory movements (No. 3769) the animal to be observed is placed in an air-tight chamber possessing two openings. Of these, one communicates (air-tight) with the respiratory cavity, the other with a manometer. This being the case, it is obvious that, the volume of the chamber being known, the variations of bulk of the animal due to respiration are accurately expressed by the variations of pressure.

Another application of a similar principle (with the exception that the closed chamber is filled with water, not with air) is one of such great importance that I shall venture to occupy a little more time in describing it to you.

The instrument in question is called the plethysmograph. Its purpose is to measure and register the changes of volume which a limb or any other living organ undergoes in vary-

ing conditions of the circulation. It has been long known that living parts vary in bulk according to the quantity of blood which they contain; but here, as in almost every other subject in physiology, all the precise knowledge we possess has been gained within a comparatively recent period. I bring it before you because the discovery of an exact method which has now been accomplished by Dr. Mosso, of Turin, is of the highest practical importance.

The arm is enclosed in a cylinder of glass entirely filled with water, the closure of the mouth of the cylinder being effected by a perforated diaphragm of india-rubber. The cavity of the cylinder communicates, by a tube, with a manometer of a peculiar kind, in the construction of which the perfection of the apparatus is most apparent. It can be readily understood by the model. Imagine in the first instance a beaker filled with distilled water, in which a test-tube containing the same liquid floats vertically. Then let us suppose that the end of the tube leading from the cylinder is bent downwards so as to dip into the liquid contained in the test-tube, so that this liquid is continuous by means of the contents of the connecting tube with the liquid which fills the cylinder. This being the case, it is obvious that the test-tube will become heavier and descend whenever the arm enlarges, and *vice versa*. Dr. Mosso has found that by properly adjusting the relative densities of the two liquids (in the beaker and test-tube), it is possible to render the gauge so extremely sensitive that the slightest fluctuations in bulk of the limb are faithfully indicated by the vertical movements of the test-tube.

In order to convert the apparatus just described into a recording instrument, all that is necessary is to write the vertical movements of the test-tube on a surface moving by clockwork. This has been successfully accomplished by Dr. Mosso, and I will now ask your attention for a moment to some of the results.

It can be shown, first of all, not only that variation of bulk of an organ is a much finer test of the state of its circulation than was previously supposed, but that the capillary circulation itself is affected by varying conditions of other functions, with a readiness which, to say the least, is very surprising. I will refer to one or two instances only. Probably everyone is aware that the circulation is much interfered with by the emotions, and that many persons blush for very inadequate reasons. Dr. Mosso has shown not only that emotions so slight that we are entirely unconscious of them produce effects on the circulation of the most definite character, but that even purely intellectual acts, such, for example, as the act of calculating, are attended with a marked diminution of the blood-stream in the superficial parts of our bodies. I will not occupy your time with describing Dr. Mosso's investigations, as I hope that some further account of them will be given by Mr. Gaskell. I am glad, however, in the absence of Dr. Mosso, to have had the opportunity of bringing his apparatus under your notice, because, in my judgment, the introduction of his method constitutes an important step towards bringing within our reach, in our investigations of the varying conditions of the circulation in man, a degree of exactitude which has been hitherto attainable only in experiments on animals.

THE MALVERN RURAL HOSPITAL.—The committee of the Malvern Rural Hospital, considering that they had not sufficient control over the medical staff, have held a special meeting, rescinded the old rules, and passed new, which, as regards the medical staff, are to the following effect:—The medical staff to consist of a consulting physician and surgeon and two other surgeons, one of whom is to be surgeon-superintendent. The staff to be appointed by the committee, upon such terms and with such duties as they may think fit. The surgeon-superintendent to visit the hospital twice a day, oftener if necessary, and see that the surgical instruments, &c., are always ready for use. No capital operation (one involving danger) to be performed without consulting the whole of the medical staff. The staff to be at liberty to invite the attendance of qualified medical practitioners, subject to regulations to be made by the committee.

MRS. "MINA JURY," whose thefts from the residences of medical men, under pretence of engaging them to attend patients, have been a matter of notoriety, has been committed for trial.