The Mechanism of the Nerves.[1]

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THE nervous system is a mass of living cells which has the extraordinary property of appearing to influence and be influenced by the mind. It is a material system somehow responsible for such non-material things as emotions and thoughts. These are in a category outside the range of mechanical explanation, and for this reason the working of the nervous system will never be fully explainable in terms of physics and chemistry. But some of the processes which take place in it can be treated in this way, and there will be no need to alter our methods of approach until we have gone a great deal further by the recognised routes. These routes are many, and the present article deals with only one of them. It deals with the analysis of the messages which travel along the nerve fibres—an analysis made possible by the recent development of the triode valve amplifier.

The active elements of the nervous system consist entirely of cells giving off fine thread-like extensions of protoplasm. These make up complex interlacing fibres forming the grey matter of the central nervous system, but most nerve cells give off one thread much larger than the rest (the axon), and this forms the channel of communication between the cell and the more distant regions. It may lead to other parts of the central nervous system or it may pass outside and lead to a sense organ or to a group of muscle fibres or secreting cells. At a short distance from the cell the axon develops a fatty sheath, and outside the central nervous system it is protected by an external covering of tubular cells, the neurilemma. The whole forms a nerve fibre with a diameter ranging from 2 to 20 microns and a length which (in man) may exceed one metre. The peripheral nerves are made up of bundles of these fibres having a common area of distribution, the number of fibres in a nerve trunk often running into several thousand. The communicating tracts of the central nervous system are similarly constituted.

We have known for some time that a nerve fibre can conduct a particular type of message under artificial conditions. A special branch of physiology has been occupied for a hundred years in investigating the changes which take place in a frog's nerve and muscle isolated from the body and stimulated mechanically or electrically. If the nerve is pinched, or if a current is passed through a short length of it, the muscle contracts. Some disturbance has passed down from the stimulated region of the nerve, and this is able to make the muscle develop its normal activity. In a frog's nerve the disturbance, or 'nervous impulse,' travels at the rate of 20-30 metres a second. No visible change accompanies it. The thermal changes are so small that it is only in the last few years that A. V. Hill has been able to detect them, and the chemical changes can only be studied by repeating the stimulation over long periods so as to obtain a measurable result.

One accompaniment of the impulse is more readily detected, however, and this is the electric response or 'action current.' Whenever the impulse arrives in a particular section of the nerve, a change of potential is developed between the active and the neighbouring inactive parts, and a current flows through the fluid surrounding the nerve or through a galvanometer connected to the active and inactive regions. As the active region travels down the fibre, the current flows shift with it, and this electric charge accompanies the impulse whatever form of stimulus is applied to the nerve. The electric charge is small enough—when every fibre in the nerve is in action simultaneously, the potential change is of the order of 10 millivolts, and the whole thing is over in a few thousands of a second. But it can be detected by instruments like the string galvanometer or the capillary electrometer, which combine sensitiveness and high periodicity, and it has given us a great deal of our information about the nature of the impulse.

Briefly, we find the impulse to be a momentary disturbance, the intensity of which at any point is determined entirely by the condition of the fibre at that point. Stimulating the nerve may be compared to firing a gun: we may pull too feebly on the trigger, but if we pull hard enough to fire the bullet no amount of extra pulling will make it travel any faster. In the same way we cannot regulate the intensity or rate of travel of the impulse by regulating the stimulus. Again, the gun needs reloading before it can be fired again, and in a nerve fibre, the passage of an impulse is followed by a very brief interval during which a further stimulus is ineffective. Each impulse is a discrete change with definite time relations, and there can be no continuous activity in the fibre, but only a succession of impulses.

The impulse takes place in a highly complex system, and no doubt it involves a whole succession of reactions which will take many more years to unravel. But it seems fairly clear that one of the principal events is the passage down the fibre of a wave of surface change which allows an interchange of ions to take place between the interior and the exterior in the active region and so to give rise to the action current. Rapidly spreading surface changes are known in many inorganic systems, and R. S. Lillie has developed a model which presents an extraordinary close analogy with the nerve fibre. When an iron wire is immersed in strong nitric acid, its surface becomes coated with a layer of 'passive' iron (probably an oxide), which prevents the acid from acting any further. If the film of passive iron is destroyed at any point, the difference of potential between the active and passive iron produces a current which has the effect of destroying the passive film

[1] Substance of two lectures delivered at the Royal Institution on Nov. 22 and 29.

in the neighbouring section of the wire, and at the same time restores it where it was first destroyed. Thus the area of surface change spreads down the wire, accompanied by an electric change which is a close copy of the action current in a nerve. Moreover, the iron wire model, like the nerve, can be stimulated by electrical as well as mechanical means.

We are still very far from knowing all that goes on when an impulse passes down a nerve fibre, but at least it has none of the variability we might expect, and we seem to be dealing with a definite series of changes following one another with mechanical regularity, changes which can be made to repeat again and again, yielding similar measurements whenever we have instruments sensitive enough to record them.

Unfortunately, the changes are so small that even the electric response can only be recorded directly when all the fibres in a nerve trunk are acting simultaneously. In the body they act more or less independently, and until recently we could not even be certain that the disturbances transmitted from sense organs or nerve cells might not differ considerably from those studied in the isolated muscle and nerve preparation. But the whole position has been altered by the advent of the triode valve amplifier. It is now possible to magnify the smallest and briefest electric changes until they are large enough to affect a recording instrument chosen not for its sensitiveness, but for its ability to give a true rendering of the most rapid fluctuations of current. The delicate string galvanometer may be replaced by the insensitive capillary electrometer, by the moving iron oscillograph recently developed by Matthews, or even by the cathode ray oscillograph used for physiological work by Erlanger and Gasser. In fact, if electric changes do occur in the normal working of the nervous system, we can no longer complain that they are too small to measure.

With the aid of valve amplification it is very easy to show that the messages which pass into or out of the central nervous system are accompanied by rapid fluctuations of potential in the nerve trunk. This, and indeed almost all the features of the nervous messages, can be demonstrated to a large audience by converting the amplified potential changes into sound waves with a loud speaker. A small piece of skin from the frog with the attached cutaneous nerve is set up in a stand with electrodes leading from the nerve to the amplifier input, and whenever the skin is touched, the nervous message set up by the sense organs in the skin becomes audible as a crackling sound in the loud speaker.

This by itself tells us very little about the nature of the message in each nerve fibre, for we are recording the confused effect of a number of fibres acting independently. To restrict the activity to one fibre we have either to divide all but one of the active nerve fibres (a difficult but not an impossible undertaking) or to arrange that the stimulus shall affect only one end organ. The former method has been used for studying the messages sent by the motor nerve cells to the muscles and the latter for the messages from sense organs. The results then become very clear and very simple. To deal first with the sensory message, we find that it consists of a series of impulses quite indistinguishable from those produced by artificial stimulation. These recur fairly regularly at a frequency which varies between 5 and 150 a second. All the impulses are alike, but the frequency with which they recur depends on the intensity of the stimulus to the sense organ. This is true of all the sense organs which have been investigated, although there are characteristic differences in the behaviour of different kinds of sense organ under a continued stimulus.

The changes in frequency will be enough to signal the intensity of the stimulus, but what is there to indicate its quality? There are two possible answers to this. One is that all the messages arising from a touch corpuscle produce sensations which we recognise as touch because they are conveyed by a particular nerve fibre and led through particular channels in the central nervous system. The other is that the impulses from different sense organs are in fact not exactly alike. The sensory nerve fibres differ considerably in diameter: Erlanger and Gasser have shown that the duration and rate of travel of the impulse varies with the diameter of the fibre, and Matthews has added the fact that sensory impulses produced by tension on a muscle travel faster than those produced by touching the skin. Whether there is a distinct size of fibre corresponding to every quality of sensation is uncertain, and it is equally uncertain whether the impulse will preserve a characteristic form as it travels through the terminal branches of the fibre, but, in the nerve trunk at least, the physiologist can tell from its form whether an impulse arises from skin or muscle, and the central nervous system may perhaps differentiate in the same way.

The investigation of the sensory message can be used to study the mode of action of the sense organs, and it can give precise information about the distribution and course of the sensory fibres, for example, in the viscera. A great deal remains to be done on these lines, but we must pass on to messages of a different origin.

The messages which pass from the motor nerve cells to the muscles are equally simple. They consist of impulses of the same kind spaced not quite so regularly, but covering very much the same range of frequency as the sensory impulses. The impulses which produce a feeble reflex or voluntary contraction recur at frequencies as low as 8-15 a second. With more intense excitation the nerve cells discharge at frequencies as high as 60-100 a second, and so produce a contraction of greater force. This agreement in the range of impulse frequency produced by the motor nerve cells and the various types of sense organ is the more striking when we remember the widely different structures involved.

Since all these messages are so much alike, we might reasonably expect to find that all the messages which pass to and fro in the tracts of the central nervous system are of the same type. For one case at least this can be verified. The optic nerve, though it passes outside the central nervous system, is really a central tract connecting it with the retina, which is an elaborate nervous outgrowth from the brain. The messages which pass down the optic nerve when the eye is exposed to light are therefore one example of the type we might expect to find within the central nervous system. They are more difficult to analyse than those in the peripheral nerves, but there is little doubt that they consist of impulses discharged in fairly regular succession at a frequency which varies with the intensity of excitation of the ganglion cells of the retina and varies over much the same range as before. To generalise on one case may bring a speedy retribution, but it is hard to resist the conclusion that all the messages in the nerve fibres are of one type, with impulses spaced more or less evenly at frequencies which vary according to the urgency of the message.

Much remains to be done before we can be certain of this, and if the generalisation is correct we shall still be very far from knowing how the messages are generated and what determines the pathways through which they travel. The great controlling and co-ordinating stations of the central nervous system may work on lines far too complex to be analysed by methods available at the moment, but at least we can say that they receive their information and issue their orders in an extremely simple manner.

Forestry Research Work in France.

IN the *Annales de l'École Nationale des Eaux et Forêts et de la Station de recherches et expériences forestières* (Tom. 2, Fasc. 1, 1928), M. H. Perrin, of the Nancy Forest School, publishes an account of the past and present position of research work under the title of " Les recherches forestières en France." It is admitted in France that, in spite of the fact that Colbert initiated the first commencement of correct forest conservation so long ago as 1660, the necessity or utility of research work into forestry problems was not only neglected, but also its value was called in question by the executive and practical forest officers who managed the forests. Research, they considered, was pure theory, and had perhaps its correct place in the laboratory; but that its results could have any practical value out in the forests was regarded as chimerical.

In the light of the present-day acceptance of the unquestioned value and necessity of research work into forestry problems, the history of the question in France is not without interest. For two centuries its few advocates remained in the wilderness. A few obtained a partial hearing during their lifetime, but little advance was made in the practical routine methods, based on acquired practice, in force in the forests. Amongst these early enthusiasts were such men as Réaumur (1683–1757), Buffon (1707–1781), Duhamel du Monceau (1700–1782), and Varenne de Fenille (1700 – 1793), who put forward tentatively new methods of management which were regarded as interesting but unpractical. The next proposals, based on German forms of management and German doctrines, were introduced into France by four men, Baudrillart (1774–1832), Lorentz (1775–1865), Parade (1802–1865), and de Buffévent (1787–1860). The German ideas were considered too theoretical to be of any use in French forestry, which, so the experts maintained, depended not on experiments and research, but on the practical observations and experience of the men in charge of the forests.

The first weakening in this attitude was due to the work of two forest officers, the first products from the Nancy Forest School which was founded in 1825 to train the officers of the Government Forest Service on scientific lines. Between 1840 and 1850, these two men, Dessales de la Gibertie and E. Chevandier de Valdrôme, enunciated the theory that research work was essential if better and more abundant timber and other produce was to be obtained from the forests, and that a formal plan of forest research should be laid down. The ultra conservatism of the French forest regime was hard to break down, and the government showed no sign of having been converted. In 1861, A. Gurnaud resigned the French Forest Service in order to conduct a vigorous campaign in favour of a system of management which has since come to bear his name, and is used in the management of areas of forest in the Jura and in Switzerland.

Gurnaud's ' method of control,' as it was termed, was the subject of heated discussion over long years; but it may be regarded as having aroused the attention of French forest officers, and led them to consider whether their unquestioned acceptance of routine methods, long in force, was in the best interests of the forests. In 1873 a government circular was issued ordering the institution of sample plots of half a hectare in extent in the younger age classes in all State forests managed under the shelter wood compartment system—a system in wide usage in France. These plots were to be measured periodically. Unfortunately, no uniformity was prescribed as to the methods to be used in making the thinnings and calculating the resultant produce. Consequently, the value of the results attained was not uniform, and was of little use for general comparison purposes. It was a first step, however, in the recognition by government that research work might prove of value.

The next step in advance was the inauguration in 1882 of the Research Station at Nancy as an annexe of the Forest School, those responsible for the new departure rightly considering that instructional and research work should go hand in hand. In order to give effect to this idea, a certain number of forests adjacent to Nancy were placed under the management of the school and research centre. The Forest Nursery at Bellefontaine, a few kilometres from Nancy, was also made over to the school; and as time went on other forest areas were included in the school forests, as they are termed. The research officers were also permitted to make use of other neighbouring State forests for