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OCCASIONAL LECTURE.

Plant and Animal Response.[1]

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AT first sight few things would appear so strikingly different as the life-activities in plants and in animals. But if, in spite of the seeming differences, it could be proved that these activities are fundamentally similar, this would undoubtedly constitute a scientific generalization of very great importance. It would then follow that the complex physiological mechanism of the animal machine, that baffled us so long, need not remain inscrutable for all time; for the intricate problems of animal physiology would then find their solution in the study of corresponding problems under simpler conditions of vegetative life. That would mean a very great advance in the science of physiology, of agriculture, of medicine, and even of psychology.

Vegetable life has always appeared to us very remote, because that life is unvoiced. The plant, in its apparent immobility and placidity, stands in strong contrast to the energetic animal with its reflex movements and pulsating organs. Yet the same environment which, with its changing influences so profoundly affects the animal, is playing upon the plant. Storm and sunshine, the warmth of summer and the frost of winter, drought and rain—all these and many more come and go about it. What subtle impress do they leave behind? Internal changes there must be, brought about by these many agencies, rendering the plant more or less excitable; but our eyes have not the power to see them.

[1] At a meeting of the Society, held March 11, 1920.

How, then, are we to know what unseen changes take place within the plant? The only conceivable way would be, if that were possible, to detect and measure the actual response of the organism to a definite testing blow. When an animal receives an external shock, it may answer in various ways; if it has a voice, by a cry; if dumb, by the movement of its limbs. The external shock is the stimulus; the answer of the organism is the response. If we can make it give some tangible answer in response to a questioning shock, then we can judge of the condition of the plant by the extent of the answer. In an excitable condition the feeblest stimulus will evoke an extraordinary large response; in a depressed state even a strong stimulus evokes only a feeble response; and lastly, when death has overcome life, there is an abrupt end of the power to answer at all.

I have shown elsewhere that definite answers to stimulus may be obtained from the plant: (1) from the mechanical response; (2) from the electro-motive response; (3) from the response by conductivity-variation; and (4) the response by variation of growth.[1] All these different methods of investigation, with different instruments for record, have been found to give identical results.

In obtaining mechanical response of plants we encounter many serious difficulties. In the animal response by muscle-contraction the pull exerted is considerable and the friction offered by the recording surface presents no serious difficulty. In the case of plants, however, the pull exerted by a motile organ is relatively feeble, and in the movement of the very small leaflets of *Desmodium gyrans*, or the telegraph plant, a weight so small as four-hundredths of a gramme is enough to arrest the pulsation of the leaflets. The difficulty could not be removed so long as the writing lever remained in continuous contact with the recording surface, but this was overcome by making an intermittent instead of a continuous contact, accomplished by an invention depending on the phenomenon of resonance. The principle of the resonant recorder depends on sympathetic vibration. If the strings of two violins are exactly tuned, then a note sounded on one will cause the other to vibrate in sympathy. We may likewise tune the vibrating writing lever with a reed. Suppose the reed and the lever are both tuned to vibrate a hundred times in a second; when the reed is

[1] Bose: "Response in the Living and Non-living" (1902); "Plant Response" (1905); "Comparative Electro-physiology" (1906); "Irritability of Plants" (1913); "Life Movements in Plants," *Transactions of Bose Institute* (1918 and 1919). (Longmans, Green and Co.)

sounded the lever will also vibrate in sympathy, and will in consequence no longer remain in continuous contact with the recording plate, but but will deliver a succession of taps a hundred times in a second. The record will therefore consist of a series of dots, the distance between one dot and the next representing one-hundredth part of a second. With other recorders it is possible to measure still shorter intervals. It will now be understood how, by the device of my resonant recorder, not only is the error due to friction eliminated, but the record itself is made to measure time as short as may be desired. The extreme delicacy of this instrument will be understood when by its means it is possible to record a time interval as short as the thousandth part of a second.

Further, devices have been introduced by which the plant attached to the recording apparatus is automatically excited by successive electric stimuli which are absolutely constant. In answer to this the plant makes its own responsive records, goes through its own period of recovery, and embarks on the same cycle over again without assistance from the observer at any point. In this way the effect of changed condition is seen recorded in the script made by the plant itself.

Having thus made it possible that the plant itself would give an answer to our questionings, we are in a position to investigate as to whether the reactions of plant and animal life are essentially similar or different.

Six years ago I had the great pleasure of giving a demonstration in this very hall by which I showed the essential similarity of physiological reactions in the plant and in the animal; an illustrated account of that lecture, "On the Action of Drugs on Plants," will be found in the *Proceedings* of the Society for 1914-15.[1] I was able to show: that the plant like the animal goes through a period of insensibility in the course of twenty-four hours; that the response of plants is subject to fatigue; that the plant perceives changes in its environment which are often imperceptible to us.

I was also able to demonstrate that there is a conducting tissue in the plant along which the excitatory impulse, analogous to the nervous impulse in the animal, is transmitted with a definite velocity. This transmission in the plant is not hydro-mechanical as has been previously supposed, for all the characteristics of the nervous impulse in the animal were shown to be present in the corresponding

[1] *Proceedings*, 1914-15, viii (Occ. Lect.), pp. 1-40.

impulse in the plant; thus rise of temperature accelerated the velocity in both, lowering of temperature causing a retardation or arrest. Anæsthetics and poisons arrested the impulse in an identical manner. I shall presently have occasion to speak of certain characteristics of "nervous" impulse in the plant which led to the discovery of corresponding reaction in the animal nerve.

I also showed that the characteristics of the rhythmic tissues in the plant are surprisingly similar to those of the cardiac tissue in the animal. The effect of various drugs on the plant and animal tissues are essentially the same. Thus an application of dilute acid induces in the animal heart an atonic reaction, in consequence of which an arrest of pulsation takes place in a relaxed or diastolic condition. The action of dilute alkaline solution is the very reverse of this—namely, a tonic contraction and arrest in systole. These characteristic effects are repeated in an astonishing manner in the pulsations of the leaflets of *Desmodium gyrans*. The application of dilute solution of lactic acid induces an arrest of the pulsation of the plant in a state of diastolic relaxation; the application of dilute NaHO solution on the other hand, induces exactly the opposite effect—i.e., an arrest at systole.

The physiological effect of a drug on the plant was further shown to be modified by the dose of application. Thus a poisonous agent which caused depression or death was shown to act as a strong stimulant when administered in minute quantities.

I also showed that the effect of a given drug was modified by the "constitution" of the plant. As a concrete example of this may be cited the different reactions given by three batches of seedlings primarily similar. These were kept for some time under three distinct conditions and afterwards subjected to the action of a given dose of dilute poison. The first batch succumbed to the poison immediately; the second struggled for a time against it, recovered and exhibited a moderate rate of growth afterwards. But the third batch was actually stimulated by the poison and demonstrated this by invigorated growth.

DEATH-SPASM IN PLANTS.

A contractile spasm takes place in the plant at the point of death under the action of poison. It may be exhibited more simply by subjecting the plant to a continuous rise of temperature. This death-point—at any rate for all the dicotyledonous plants observed and their different organs—was found to be almost as definite as a physical constant; for, using very diverse specimens and methods, this critical temperature is always at or very near 60° C. The death-contraction in the plant is in every respect similar to the same phenomenon in the animal, and is an instance of true excitatory effect. Yet different plants have their characteristic death-curves, and the same species may exhibit variations under changed conditions of age and previous history. Thus when the plant's power of resistance is artificially depressed, whether by poisons or by fatigue, its death-spasm occurs at a temperature often considerably lower—even as much as 23°. An electric spasm also occurs corresponding to the mechanical spasm at death. The electromotive force generated at death-temperature is sometimes considerable: in each half of a green pea this may be as high as half a volt. If five hundred pairs of half peas are suitably arranged in series, the electric pressure will be five hundred volts, which may even cause electrocution of unsuspecting victims. It is well that the cook does not know the danger she runs in preparing the particular dish; it is fortunate for her that the peas are not arranged in series!

Localization of Organ of Perception in Plants.

The most difficult problem in connexion with the tropism exhibited by plants is its perception of direction of gravity. When the plant is laid flat it perceives in some unknown way the direction of gravity and responds by bending upwards. For the clear understanding of the physiological reaction which induces the orientating movement, it is necessary to get hold, as it were, of a single cell or a group of cells *in situ* and in a condition of fullest vital activity; to detect and follow by some subtle means the change induced in the perceptive organ and the irradiation of excitation to neighbouring cells, through the entire cycle of reaction, from the onset of geotropic stimulus to its cessation. The idea of obtaining access to the unknown geo-perceptive cell in the interior of the organ for carrying out various physiological tests appeared at first to be very extravagant. But I was able to attack the problem with success by the invention of an electric probe which enabled me to explore the excitatory electric distribution in the interior of the organ. I have shown that the state of excitation in a plant is exhibited by an electric variation of galvanometric negativity. With the help of the electric probe, I was able to explore the interior of the plant and detect the state of excitation in its different layers. As long as the stem remains vertical, geotropic stimulation is absent, but inclination to the vertical initiates the irritation. The electric probe consists of an exceedingly fine platinum wire, enclosed in a capillary glass tubing; the probe is thus electrically insulated except at the extreme tip. When the probe, suitably connected with a galvanometer, is slowly thrust into the stem so that it enters one side and comes out at the other, the galvanometer will by its deflection show the state of irritation of every layer of cell throughout the organ. Holding the stem vertical, I sent the exploring probe step by step across the organ but found little or no sign of local excitation.

The case is very different when the stem is displaced from the vertical to a horizontal position. The geotropically sensitive layer now perceives the stimulus and becomes the focus of irritation; the state of excitation is, as explained before, detected by negative electric change exhibited by the galvanometer, and the electric variation would be most intense at the perceptive layer itself; the excitation at the perceptive layer will irradiate into the neighbouring cells in radial directions with intensity diminishing with distance. Hence the intensity of responsive electric change will decline in both directions outwards and inwards.

The distribution of the excitatory change, initiated at this perceptive layer and irradiated in radial directions, may be represented by light and shade, the darkest shadow being on the perceptive layer itself. Had excitation been attended with change of light into shade, we would have witnessed the spectacle of a deep shadow, vanishing towards the edges, and spreading over the different layers of cells during displacement of organs from vertical to horizontal; the shadow would have disappeared on the restoration of the organ to the vertical position.

Different shades of excitation in different layers are, however, capable of discrimination by means of the insulated electric probe, as it is pushed into the organ from outside. In actual experiment the probe exhibited increasing excitatory electric change during approach to the perceptive layer, which reached its climax when the probe came in contact with that layer. When it passed beyond this point the electric indication of excitation underwent rapid decline and abolition. The electric indication at the perceptive layer itself became abolished as soon as geotropic stimulus was removed by the restoration of the organ to the vertical position. I was thus able to map out the contour lines of physiological excitation inside a living organ.

CONTROL OF NERVOUS IMPULSE.

I have briefly referred to the characteristics of "nervous" impulse in plants which are similar to those in the animal. I have been able to induce artificial paralysis in the plant nerve, and try the efficacy of various curative agents on it. These investigations with the simple type of plant-nerve are calculated to throw considerable light on the obscure phenomenon of nervous impulse in general, and the causes operative in bringing about the degeneration of the normal function of the nerve.

In carrying out investigations on the characteristics of the impulse transmitted along the conducting tissue of the plant, I found that it was of a dual character, a positive followed by a negative. The positive gives rise to expansion, and erectile movement of the mobile leaf; the negative, on the other hand, gives rise to contraction and down-movement of the leaf. The positive is more easily obtained under a very feeble stimulus. I have recently obtained effects somewhat similar with the animal nerve; the investigation is still in progress, and I am trying to devise a special apparatus by means of which these effects could be recorded.

The nervous impulse causes response which may be either mechanical or sensory, according to the nature of the terminal organ, muscle or brain. Our sensation is coloured by the intensity of nervous excitation which reaches the central perceiving organ. And this is determined by two different conditions—namely, the intensity of external stimulus, and the power of conduction possessed by the message-bearing vehicle, the nerve. We may consider two extreme cases; there are happenings which elude us because the impinging stimulus is too feeble for the resulting nervous impulse to cause perception. In this case we desire to exalt the conducting power of the nerve, so that what was sub-minimal shall become perceptible. On the other hand, the external stimulus, on account of its character or intensity may cause sensation which is intolerably painful. Could the painful tone be modified in transit or blocked altogether?

There is some resemblance between the conduction of electric impulse in a metallic conductor and nervous impulse in a nerve conductor. In metal, the power of conduction is constant, and the electric impulse will depend on the intensity of electric force that is applied. If the conducting power of the nerve were constant then the intensity of the nervous impulse and the resulting sensation will depend inevitably on the shock that starts the impulse. In that case the modification of sensation would be an impossibility. But there may be a likelihood that the power of conduction possessed by a nerve is not constant but capable of change. Should this surmise prove to be correct, then we arrive at the momentous conclusion that sensation itself is modifiable whatever be the external stimulus. For the modification of nervous impulse there remains only one alternative—namely, some power to render the vehicle a very much better conductor, or a non-conductor, according to particular requirements. We require the nervous path to be supra-conducting, to have the impulse due to subminimal stimulus brought to sensory prominence. When the external blow, on the other hand, is too violent, we would block the pain causing impulse by rendering the nerve a non-conductor.

Under narcotics the nerve becomes paralysed, and we can thus by its use save ourselves from pain. But such heroic measures are to be resorted to in extreme cases, as when we are under the surgeon's knife. In actual life we are confronted with unpleasantness without notice. A telephone subscriber has the evident advantage, for he can switch off the connexion when the message begins to be unpleasant. But it is not everyone who has the courage of Mr. Herbert Spencer, who openly resorted to his ear-plugs when his visitor became tedious.

Let us now form a mental picture of the character of that disturbance by which nervous message is transmitted. A blow or shock from outside causes a molecular upset in the nerve-ending. The transmission of nervous impulse is regarded as a propagation of molecular disturbance from point to point along the conducting nerve.

On Molecular Predisposition.

Let us go one step further in our reasoning, from molecular propagation of disturbance, to the effect of molecular predisposition on the speed and intensity of transmitted disturbance. It is obvious that conduction would become facilitated or retarded by imparting to the molecules a predisposition in a favourable or in an unfavourable direction. The molecular upset and propagation of disturbance may be represented simply by means of a row of books. A certain intensity of blow applied, say, at the right, would cause the book to fall to the left, hitting its neighbour, causing other books to topple over in succession. If the books have previously been slightly tilted to the left, a particular predisposition would have been given them which would enable a feeble blow to cause the upset; moreover the books would topple over more quickly, and the speed would be accelerated. But if, on the other hand, the books had been tilted to oppose the blow, then the stimulus that was effective would now become ineffective.

The theoretical considerations which I have adduced will show how in consequence of definite and ordered disposition in one direction or the other of the constituent units making up the conducting system, the excitation induced by the same stimulus may be accelerated or inhibited during transit. The essential thing is to get hold as it were of the molecules, and coerce them at one's bidding to arrange themselves in the positive and favourable direction, or in the negative and unfavourable direction. By the application of an external force of a polar character—an electric current flowing in one direction or its opposite—I have been successful in inducing at will and in turn two different molecular dispositions. I shall now describe the actual experiments, carried out first with the nerve of the plant. I produced a favourable disposition of the molecules in the nervous tissue, and feeble stimulus below the threshold now produced an extraordinary large response; conversely a violent excitation was at once quelled during transit by inducing the opposite molecular disposition, and thus abolishing the conducting power of the vehicle. I was thus able to confer on the identical nerve a *supra*-conducting or *non*-conducting power at will. No test could be more severe in the complete establishment of the theory I held about the fundamental unity of life-reactions in the plant and animal than the production of identical results in the nerve of the animal. Thus experimenting on the frog I found that under favourable molecular disposition of the nerve, the animal responded vigorously to stimulus which had hitherto been below its threshold of perception. Under the opposite disposition the violent salt-tetanus became instantly quelled. On the cessation of the directive force, the nerve returned to its normal condition.

These "molecular predispositions," it is evident, can also be produced by suggestion, and the efficacy of this mode of treatment is known to you in the case of nervous patients. "Faith-cure" is only a variety of it. Similarly auto-suggestion, or effort of the will, has profound influence on molecular disposition of the nerve. Who can define the limit of this power of will, intensified by practice and concentration?

In the determination of sensation then, the internal stimulus of will may play as important a part as the shock from outside. And thus through the inner control of the molecular disposition of the nerve, the character of the resulting sensation may become profoundly modified. The external then is not so overwhelmingly dominant, and man is no longer passive in the hands of destiny. There is a latent power which would raise him above the terrors of his inimical surroundings. It remains with him that the channels through which the outside world reaches him should, at his command, be widened or become closed. It would thus be possible for him to catch those indistinct messages that had hitherto passed by him unperceived; or he may withdraw within himself so that in his inner realm the jarring notes and the din of the world should no longer affect him.

The High Magnification Crescograph.

We have next to investigate a very important class of phenomena, namely of growth and its variations. The difficulty of the investigation arises from the extreme slowness of growth. We take a single step, covering 2 ft. in about half a second; during this period the plant grows through a length of $\frac{1}{100000}$ part of an inch, or half the length of a single wave of light. It is evident that some very strongly magnifying arrangement must be employed to observe growth and its changes. The instrument hitherto used in the botanical laboratory—the "auxanometer"—magnifies about twenty times or so. Even here several hours must elapse before growth becomes perceptible; but during this long period the external conditions such as light and warmth can hardly but change, thus confusing, if not even vitiating, the results.

The external conditions can be kept constant only for a few minutes; and it is therefore necessary to obtain growth-magnification to something like 10,000 times. The difficulty of obtaining such magnification is so great that it took me several years to overcome them. This apparatus not only produces this enormous magnification, but also automatically records the rate of growth and its changes, in a period as short as a minute. In this instrument I employ a compound system of two levers; the first magnifies a hundred times, and the second enlarges the first a hundredfold, the total magnification being thus 10,000 times. But the double system of levers introduces difficulty on account of their weight; this was surmounted by the employment of an alloy of aluminium, which combines great rigidity with exceptional lightness. The friction at the bearings increased by the deposit of invisible dust particles introduced a further difficulty; bearings even made of ruby did not obviate the trouble. I was finally able to devise a new form of support by which all difficulties were fully overcome.

AUTOMATIC RECORD OF THE RATE OF GROWTH.

Another great difficulty in obtaining an accurate record of the curve of growth arises from the friction of contact of the bent tip of the writing lever against the recording surface. This I was able to overcome by an oscillating device in which the contact, instead of being continuous, is made intermittent. The smoked glass plate, G, is made to oscillate to and fro at regular intervals of time, say one second. The bent tip of the recording lever comes periodically in contact with the glass plate

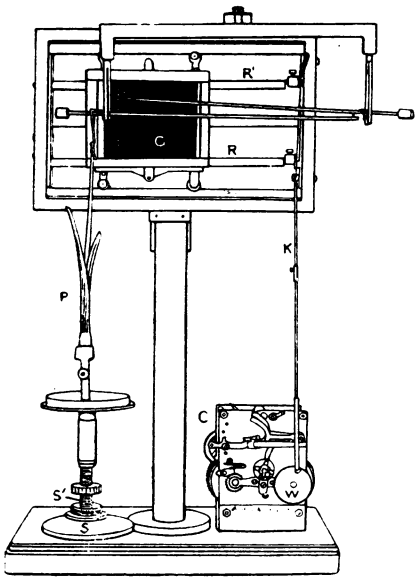

FIG. 1.

Complete apparatus. P, plant; S, S′, micrometer screws for raising or lowering the plant; C, clockwork for periodic oscillation of plate; W, rotating wheel; K, crank.

during its extreme forward oscillation. The record would thus consist of a series of dots, the distance between successive dots representing magnified growth during a second.

The drawback in connexion with the obtaining of a record on the oscillating plate lies in the fact that if the plate approaches the recording point with anything like suddenness, then the stroke on the flexible lever causes an after-oscillation; the multiple dots thus produced spoil the record. In order to overcome this, a special contrivance is necessary, by which the speed of approach of the plate should be gradually reduced to zero at contact with the recording point. The rate of recession should, on the other hand, continuously increase from zero to maximum. The recording point will in this manner be gently pressed against the glass plate, marking the dot, and then gradually be set free. It is only by strict observance of these conditions that the disturbing effect of after-vibration of the lever can be obviated.

This particular contrivance consists of an eccentric rod actuated by a rotating wheel. A cylindrical rod is supported eccentrically, so that semi-rotation of the eccentric causing a pull on the crank K pushes the plate-carrier gradually forward. On the return movement of the eccentric, a light antagonistic spring makes the plate recede. The rate of movement of the crank itself is further regulated by a revolving wheel which is released periodically by clockwork at intervals of one, two, five, ten, or fifteen seconds respectively, according to the requirements of the experiment. The complete apparatus is shown in fig. 1, p. 111.

I will now proceed to describe certain typical experiments which will show: (1) the extreme sensibility of the crescograph; (2) its wide applicability to different investigations; and (3) its capability of determining with great precision the time-relations of responsive changes in the rate of growth. In describing these typical cases, I give a detailed account of the experimental methods employed, and thus avoid repetition in describing subsequent experiments.

Determination of the Absolute Rate of Growth.

I will describe the results of a record on a stationary plate obtained with *Scirpus Kysoor*. The oscillation-frequency of the plate was once in a second, and the magnification employed was 10,000 times. The magnified growth-movement was so rapid that the record consists of a series of short dashes instead of dots (fig. 2, *a*). For securing regularity in the rate of growth, it is advisable that the plant should be kept in uniform darkness or in uniformly diffused light. So sensitive is the method of record that it shows a change of growth-rate due to the slight increase of illumination by the opening of an additional window. One-sided light, moreover gives rise to disturbing phototropic curvature. With the precautions described, the growth-rate in vigorous specimens is found to be very uniform.

After the completion of the first vertical series, the recording plate was moved 1 cm. to the left; the tip of the recorder was brought once more to the top by means of the fine screw adjustment S (fig. 1), and the record taken once more after an interval of fifteen minutes. The magnified record for four seconds is 38 mm. in the first record. It is precisely the same in the record taken fifteen minutes later. The successive growth-elongations at intervals of one second are practically the same throughout, being 9·5 mm. This uniformity in the spacings demonstrates not only the regularity of growth under constant conditions, but also the reliability and perfection of the apparatus. It also shows that by keeping the external conditions constant, the normal growth-rate could be maintained uniform for at least fifteen minutes. As the magnified growth is nearly 1 cm. per minute, and as it is quite easy to measure 0·5 mm., the crescograph enables us to record a movement of

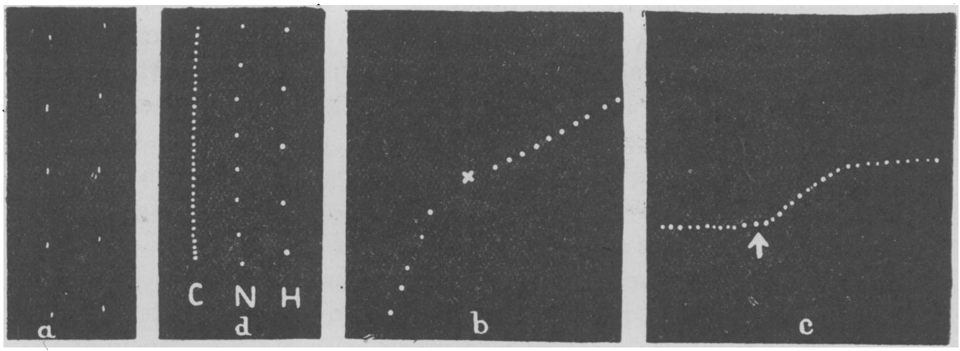

FIG. 2.

Crescographic records. *a*, successive records of growth at intervals of one second, × 10,000, with a stationary plate, *d*. Effect of temperature: N, normal rate of growth; C, retarded rate under cold; H, enhanced rate under warmth; *b*, record on moving plate, where diminished slope of curve denotes retarded rate under cold; *c*, horizontal record showing absence of growth in dead branch; physical expansion on application of warmth at arrow, followed by horizontal record on attainment of steady temperature. (× 2,000.)

0·00005 mm., that is to say, the sixteenth part of a wave of red light. The absolute rate of growth, moreover, can be determined in a period as short as 0·05 second. These facts will give us some idea of the enormous possibilities of the crescograph for future investigation.

As the period of the experiment is very greatly shortened by the method of high magnification, I shall, in the determination of the absolute rate of growth, adopt a second as the unit of time and μ or micron as the unit of length—the micron being 0·000001 metre, or 0·001 mm.

If m be the magnifying power of the compound lever, and l the average distance between successive dots in millimetres at intervals of t seconds, then

$$\text{rate of growth} = \frac{1}{mt} \times 10^3\mu \text{ per sec.}$$

In the record given $l = 9{\cdot}5$ mm., $m = 10{,}000$, $t = 1$ second.
Hence rate of growth

$$= \frac{9{\cdot}5}{10{,}000} \times 10^3\mu \text{ per sec.} = 0{\cdot}95\ \mu \text{ per sec.}$$

Precaution against Physical Disturbances.—There may be some misgiving about the employment of such high magnification; it may be thought that the accuracy of the record might be vitiated by physical disturbance, such as vibration. In physical experimentation far greater difficulties have been overcome, and the problem of securing freedom from vibration is not at all formidable. The whole apparatus need only be placed on a heavy bracket screwed on the wall to ensure against mechanical disturbance. To what extent this has been realized will be found from the inspection of the first part of the record in fig. 2, *c*, taken on a moving plate. A thin dead twig was substituted for the growing plant, and a perfectly horizontal record not only demonstrated the absence of growth-movement but also of all disturbance. There is also another element of physical change, against which precautions have to be taken in experiments on variation of the rate of growth with rising temperature. In order to determine its character and extent, a record was taken, with the dead twig, of the effect of raising the temperature of the plant-chamber through 10° C. The record, with a magnification of 2,000, shows that there was an expansion during the rise of the temperature, after which there was a cessation of physical movement, the record becoming once more horizontal. The obvious precaution to be taken in such a case is to wait for several minutes for the attainment of steady temperature. The movement caused by physical change abates in a short time, whereas the change of rate of growth brought about by physiological reaction is persistent.

Having demonstrated the extreme sensitiveness and reliability of the apparatus in quantitative determinations, I proceed to show its wide applicability for various researches relating to the influence of external agencies in modification of growth. For this two different methods are employed. In the first, the records are taken on a stationary plate; the first in the series gives the normal rate; the second is the record taken under the given changed condition. The increase or diminution of the space between successive dots in the two records at once demonstrates the stimulating or depressing nature of the changed condition. In the second method, the record is taken on a plate moving at a uniform rate by clockwork. A curve is thus obtained, the ordinate representing growth-elongation and the abscissa the time. The increment of length divided by the increment of time gives the absolute rate of growth at any part of the curve. As long as growth is uniform, so long the slope of the curve remains constant. If a stimulating agency enhances the rate of growth, there is an immediate flexure in the curve. A depressing agent lessens the slope of the curve.

I will now give a few typical examples of the employment of the crescograph for the investigation of growth; the first example I shall take is the demonstration of the influence of temperature.

Stationary Method.—Fig. 2, *d*, gives records taken on a stationary plate. The plant used was *Kysoor;* the crescograph magnification was 2,000, and the successive dots at intervals of five seconds. The middle series, N, was at the temperature of the room. The next, C, was obtained with the temperature lowered by a few degrees. Finally, H was taken when the plant-chamber was warmed. It will be seen how under cooling the spaces between successive dots have become shortened, showing the diminished rate of growth. Warming, on the other hand, caused a lengthening of the spaces between successive dots, thus demonstrating an enhancement of the rate of growth.

Calculating from the data obtained from the figure, we find:—

Absolute value of normal rate	0·457 μ per second.
Diminished rate under cold	0·101 ,, ,,
Enhanced rate under warmth	0·737 ,, ,,

Moving Plate Method.—Another experiment was carried out with a different specimen of *Kysoor*, the record being taken on a moving plate (fig. 2, *b*). The left part of the curve here represents the normal rate of growth. The plant was then subjected to moderate cooling, and the subsequent curve with its diminished slope denotes the depression of growth.

Determination of Latent Period and Time-relations of Response to Stimulus.

In the determination of time-relations of responsive change in growth under external stimulus, I take the typical case of the effect of electrical shock of one second's duration from a secondary coil.

Two electrodes were applied, one above and the other below the growing region of a bud of *Crinum.* The record was taken on a moving plate, magnification employed being 2,000, and successive dots made at intervals of two seconds. It was a matter of surprise to me to find that the growth of the plant was affected by an intensity of stimulus far below the limit of our own perception. For convenience I shall designate the intensity of electric shock that is barely perceptible to us, as the unit shock. When an intensity of 0·25 unit was applied to the growing organ, it responded by a retardation of the rate of growth. As regards the relative sensibility of plant and animal, I may say that the leaf of *Mimosa pudica,* in a favourable condition, responds to an electric stimulus which is one-tenth the minimum intensity that causes perception in a human being.[1]

Inspection of fig. 3, *a*, shows that a flexure is induced in the curve in response to stimulus, the flattening of the curve denoting retardation of growth. The latent period in this case was six seconds. The normal rate was found restored after a rest of five minutes. The intensity of shock was next raised from 0·25 unit to 1 unit. The second record shows that the latent period was reduced to four seconds, and a relatively greater retardation of growth was induced by the action of the stronger stimulus. The recovery of the normal rate was effected after the longer period of ten minutes. I took one more record, the stimulus being 3 units. The latent period was now reduced to one second, and the induced retardation was so great as to effect a temporary arrest of growth, after which there was a slow recovery. Under still stronger stimulation, the retardation culminates into an actual contraction, the responsive contraction persisting for a considerable length of time. What has been said of electric stimulus is equally true of all modes of stimulation, mechanical, photic or chemical.

As a further example of the capability of the crescograph, I will give a record of a single pulse of growth obtained with the peduncle of *Crocus* (fig. 3, *b*). The magnification employed was 10,000, the successive dots being at intervals of one second. It will be seen that the growth-pulse commences with a sudden elongation, the maximum rate being 0·4 μ per second. The pulse exhausts itself in fifteen seconds, after which there is a partial recovery in the course of thirteen seconds. The period of the complete pulse is, therefore, twenty-eight seconds. The resultant growth in each pulse is, therefore, the difference between

[1] Bose, "Irritability of Plants," 1913, p. 50.

elongation and recovery. Had a highly magnifying arrangement not been used, the resulting rate would have appeared continuous. In other specimens, owing probably to greater frequency of pulsation and co-operation of numerous elements in growth, the rate appears to be practically uniform.

TABLE I.—TIME-RELATIONS OF GROWTH VARIATION UNDER ELECTRIC SHOCK.

(*Crinum.*)

Intensity of stimulus	Latent period	Normal rate	Retarded rate
0·25 unit ...	6 seconds ...	0·62 μ per second. ...	0·49 μ per second.
1 ,, ...	4 ,, ...	0·62 ,, ,, ...	0·25 ,, ,,
3 units ...	1 second ...	0·62 ,, ,, ...	Temporary arrest of growth

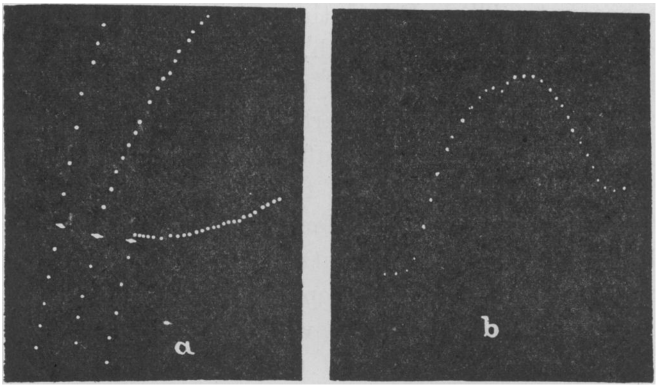

FIG. 3.

a, Time-relations of response of growing bud of *Crinum* to electric stimulus of increasing intensity applied at the short lines; *b*, record of a single growth-pulse of *Crocus*.

It will be seen from the above that growth in plants may be affected by an intensity of stimulus which is below human perception; that with increasing stimulus the latent period is diminished and the period of recovery increased; that the induced retardation of growth increases continuously with the stimulus till at a critical value there is a temporary arrest of growth; with greater intensity of stimulus there is induced an actual contraction.

By the employment of the method just described the effect of manures and chemicals, drugs and poisons, may now each be determined in the course of a few minutes, and with unprecedented accuracy. Here too, as in the preceding cases, we realize the value of this high magnification apparatus: not simply because all the phenomena are rendered far clearer and more conspicuous, but also because the result of any particular change of conditions can be detected in the course of a few minutes, during which the other conditions may remain constant, or be artificially kept so.

It will be understood that it is only by the discovery of laws of growth that any marked advance in scientific agriculture is possible. We have been using only a few stimulating agents, whereas there are thousands of the actions of which we have no conception. The rule of thumb method hitherto employed in the application of a few chemical stimulants and of electricity has, moreover, not been uniformly successful. The cause of the anomaly is found from the discovery of an important factor—namely, the dose of application, which had hitherto not been taken into account. Thus I find that while a particular intensity of electrical current accelerated growth, any excess above a critical point retarded it. The same is true of chemical stimulants. A striking practical result was obtained with certain poisons which in normal doses killed the plant, but in quantities sufficiently minute acted as an extraordinarily efficient stimulant, the treated plants growing far more vigorously and flowering much earlier. The treated plants, moreover, successfully resisted the insect blights. These facts lead to the inquiry into the critical point at which a depressant passes into a stimulant, or conversely. At this point we see how a fresh line of research has here been opened for pharmacology and medicine. And similarly another for speedily testing the action of manurial agents, and other means of accelerating growth for agriculture. The immediate test needs only a few minutes instead of a season, while the changing conditions of the latter are avoided.

The Balanced Crescograph.

The researches described showed that the growth of plants was affected by changes in the environment which were below the range of human perception. For this new range of investigation I had to turn my attention to a new type of apparatus, the sensitiveness of which had to surpass those which I had already invented. The high magnification crescograph enabled me to measure the most minute rate of growth. For the detection of the effect of impact of external stimulus it was necessary first to measure the normal rate, and afterwards the changed rate induced by the stimulus. The effect of stimulus, whether stimulating or depressing, could be found from calculation of the difference in the two cases. I next wished to eliminate the necessity for calculation and the consequent loss of time by devising a new method which would *instantly* show by the up or down movement of an indicator the accelerating or retarding effect of the agent on growth.

The desideratum was to compensate the up-movement of growth by some regulating device; this involved the problem of making the plant descend at the exact rate at which the growing plant was rising, whatever that rate might be. Some such regulator has to be introduced as in the compensating movement of an astronomical telescope, by which the effect of earth's movement round her axis once in twenty-four hours is neutralized. But the problem that confronted me was far more difficult, for instead of compensating a definite rate I had to obtain adjustment for widely varying rates of growth in different plants, and even of the same plant under different conditions.

The difficult problem was successfully solved in my balanced crescograph. A train of revolving clockwheels, actuated by the fall of a weight, lowers the plant exactly at the same rate at which it is growing. The exact adjustment is obtained by regulation of a governor; the gradual turning of a screw to the right or to the left causes the rate of compensating fall to be retarded or accelerated. In this way the rate of growth becomes exactly compensated, and the recorder now dots a horizontal line instead of the former curve of ascent. The turning of the adjusting screw of the balanced crescograph also moves an index against a circular scale so graduated that its reading at once gives the rate at which the plant is growing at that instant. When balanced, the recording apparatus is extraordinarily sensitive. Any change, however slight, in the environment is at once indicated by the upset of the balance with up or down movement of the curve. This method is so sensitive that it has enabled me to detect variation of rate of growth as minute as 1,500-millionth of an inch per second.

As an illustration of the delicacy of this method, a record (fig. 4) is given of the effect of carbonic acid gas on growth. A jar is filled with this gas and emptied over the plant; the invisible gas, on account of its heavier weight, falls in a stream and surrounds the plant. The record shows that this gave rise to an immediate acceleration of growth, and this continued for two and a half minutes; this preliminary acceleration was followed by retardation of growth, as shown by the down curve. With diluted carbonic acid, the acceleration may persist for an hour or more. Thus the balanced crescograph not only shows us the beneficial effect of an agent, but also tells us the dose which prolongs the beneficial effect.

Plants are regarded as extremely sluggish: and it is supposed that they are unable to perceive a stimulus unless applied for a considerable length of time. Thus, for the perception of geotropic stimulus, it is supposed that, "even in rapidly reacting organs there is always an interval of about one to one and a half hours before the horizontally placed organ shows a noticeable curvature, and this latent period may in other cases be extended to several hours (Jost)." I find that the latent period of geotropic perception is often as short as a second.

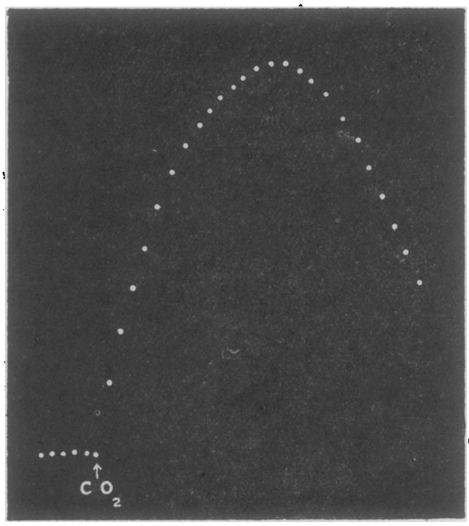

FIG. 4.

Record by Balanced Crescograph of the effect of CO_2 on growth. The horizontal line is the record under exact balance, which is upset by the action of CO_2.

As regards perception of light, it has been supposed that the period of effective exposure must at least be of seven minutes' duration. With my extremely sensitive apparatus I investigated the question of plants' capability to respond to stimulus of light of excessively short duration. We can hardly conceive of anything so fleeting as a single flash of lightning. The growing plant, balanced in the crescograph, was subjected to an artificial flash of lightning—that is to say, to the light emitted by a single electric spark between two metallic balls. The plant perceived this light of incredibly short duration, as was manifest from the upset of the balance, and the resulting automatic script made by the plant.

So much as regards the perception of plants to minimum duration of stimulus. The next question is as regards their range of perception. My discovery of the response of plants to wireless stimulation has recently roused much interest. At first sight the possibility of the plant to perceive and respond to the long ether waves employed for wireless signalling would appear to be very unlikely. For the rays hitherto regarded as most effective on the plant are in the ultra-violet region with wave-length as short as 20×10^{-6} cm.; but with electric waves used in wireless signalling we have to deal with waves 50,000,000 times as long. The perceptive power of our retina is confined within the

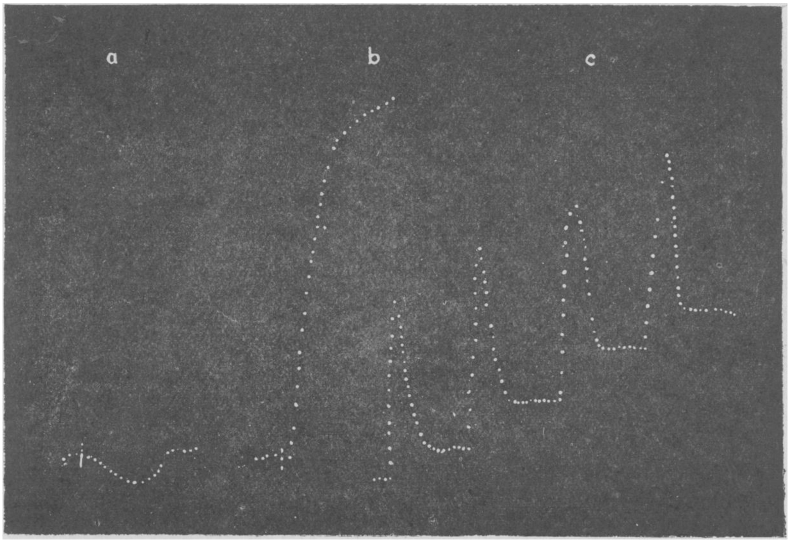

FIG. 5.

Record of responses to wireless stimulation by means of the Balanced Crescograph. (a) Response to feeble stimulus by acceleration of growth; (b) response to strong stimulus by retardation; (c) response to medium stimulation —retardation followed by recovery. Down-curve represents acceleration, and up-curve retardation of growth. (Seedling of wheat.)

very narrow range of a single octave, the wave-lengths of which lie between 70×10^{-6} cm. and 35×10^{-6} cm. It is difficult to imagine that plants could perceive radiations so widely separated from each other as the visible light and the invisible electric waves.

But the experimental investigations which I have carried out prove conclusively that plants perceive and respond to wireless stimulation. This will be seen from the records (fig. 5) here reproduced given by the balanced crescograph. The perceptive range of the plant is thus inconceivably greater than ours; it not only perceives but also responds to the different rays of the vast æthereal spectrum.

THE MAGNETIC CRESCOGRAPH.

The magnification obtained with two levers, as stated before is 10,000 times. It may be thought that further magnification would be possible by a compound system of three levers. But the friction at the fulcrum becomes added up by an increase in the number of levers, and this interferes with the uniformity of the movement of the last recording lever. For securing further magnification additional material contact has, therefore, to be abandoned and some mode of linking, as it were, through space to be adopted. I have recently been successful in devising an ideal method of magnification without additional contact. The movement of the single lever of the crescograph upsets a very delicately balanced magnetic system. The indicator is a spot of light reflected from a mirror carried by the deflected magnet (fig. 6). In this way I have been successful in obtaining magnification which may be varied from one to fifty million times.[1]

Our mind cannot grasp magnification so stupendous. We can, however, obtain some concrete idea of it by finding what the speed of the proverbial snail becomes when magnified ten million times by the magnetic crescograph. For this enhanced speed there is no parallel even in modern gunnery. The 15-in. cannon of the *Queen Elizabeth* throws out a shell with a muzzle velocity of 2360 ft. per second or about 8,000,000 ft. per hour; but the crescographic snail would move at a speed of 200,000,000 ft. per hour, or twenty-four times faster than the cannon shot. Let us turn to cosmic movements for a closer parallel. A point on the equator whirls round at the rate of 1037 miles per hour. But the crescographic snail may well look down on the sluggish earth; for, by the time the earth makes one revolution, the snail would have gone round nearly forty times!

[1] "Sir Jagadis Bose's crescograph is so remarkably sensitive that doubt was recently expressed as to the reality of its indications as regards plant growth; and the suggestion was made that the effects shown by it were due to physical changes. A demonstration at University College, London, on April 23 has, however, led Lord Rayleigh and Professors Bayliss, V. H. Blackman, A. J. Clark, W. C. Clinton and F. G. Donnan to state in the *Times* of May 4: 'We are satisfied that the growth of plant tissues is correctly recorded by the instrument and at a magnification of from one to ten million times.' Sir W. H. Bragg and Professor F. W. Oliver, who have seen similar demonstrations elsewhere, give like testimony that the crescograph shows actual response of living plant tissues to stimulus."—*Nature*, May 6, 1920, p. 305.—J. C. B.

The magnetic crescograph is before you. If I attach to the apparatus a specimen of plant which had been killed and in which there is therefore no growth, the indicating spot of light remains quiescent. But when I attach the growing plant, see how the spot of light moves with steady speed towards the right, the magnification employed being now two million times. While it is moving to the right I give it an electric shock, which we saw arrests growth: the movement of the spot of light also comes to a stop. Under stronger and long continued shock the spot of light flies to the left, showing the actual contraction of the organ. A very similar effect is produced by the stimulus of light, the ultra-violet light being most effective in retardation of growth.

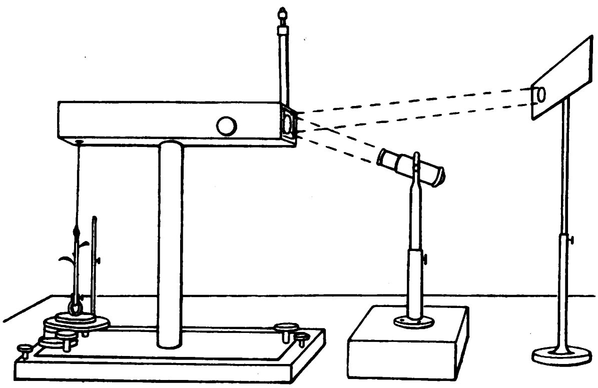

FIG. 6.

The Magnetic Crescograph. A magnetized lever causes by its movement rotation of suspended magnetic needle with attached mirror.

I take another specimen: you note the normal rate of its growth movement. I now apply a stimulating drug: observe how the movement is greatly enhanced; a depressing drug on the other hand slows down growth. The life of the plant thus becomes subservient to the will of the experimenter, so that he can exalt or depress its activity, bring it near the point of death by application of poison, and when the plant is hovering in an unstable poise between life and death resuscitate it by the timely application of an antidote. Here is played before us the drama of life and death, revealing to us much that had been obscure.

These, our mute companions, silently growing beside our door, have now told us the tale of their life-tremulousness and their death-spasm in script that is as inarticulate as they. May it not be said that their story has a pathos of its own beyond any that we have conceived?

In realizing this unity of life is our final sense of mystery deepened or lessened? Is our sense of wonder diminished when we realize in the infinite expanse of life that is silent and voiceless the foreshadowing of more wonderful complexities? Is it not rather that science evokes in us a deeper sense of awe? Does not each of her new advances gain for us a step in that stairway of rock which all must climb who desire to look from the mountain-tops of the spirit upon the promised land of truth?

DISCUSSION.

The PRESIDENT: You have shown by your applause the intense interest aroused in these demonstrations, revelations which almost bewilder one as to their eventual outcome. These records have been made possible by the extraordinarily skilful adaptation of the graphic method, and as we have with us a master of that method, Dr. Waller, he will perhaps voice our interest and appreciation of Sir Jagadis Bose's demonstration.

Professor A. D. WALLER, F.R.S.: You, Sir, have already given expression to the feeling of gratitude we have to Sir Jagadis Bose for his lecture and for the great trouble he has taken to put before us a demonstration of his beautiful instrument. I have been doing a little sum to enable me to realize what a magnification of ten million times means. It would mean a blood corpuscle 70 metres in width. One μ multiplied by a million would be a metre, multiplied by ten millions would be 10 metres. Errors would be in the same proportion. It is an astounding magnification, and I came here to-day in order that I might satisfy myself whether or not the movement upon the screen truly represented growth. It is at a quite reasonable rate; the spot of light appeared to me to move at the rate of about a metre per second. But the behaviour of the spot of light was, to me, highly suspicious, if I may venture to say so. It moved at the rate it ought to, and at the rate I expected it to move, and the experiment at the end was precisely what I expected it to be. That is to say, not only was there an arrest of the growth, but there was the converse of growth, there was de-growth; to the right as I read it, was the direction of elongation, to the left the direction of contraction. What I would like is, that Sir Jagadis would repeat to us on non-living cells under the less difficult conditions of the laboratory the experiment he has just shown us on living matter under the difficult conditions of the lecture room—you see I am taking free advantage of your permission, Sir, to criticize. Let me add, however, that criticism is a compliment we Westerns freely pay to each other, though it may seem to an Eastern fellow-subject of the Empire a little out of place if he does not see quite eye to eye with us. But it is, in reality, the greatest compliment I can pay Professor Bose to take his demonstration quite seriously. When the induction shocks were passed there was the reversal of growth, the spot moved in the sense of shortening of the plant; and if we had been in the laboratory I should have said "kill that plant, put it into hot water, then repeat the experiment and see how it acts." [Sir JAGADIS BOSE: I can kill it.] I quite understand that under present conditions it would be impossible to carry that out, but it could easily be done in the laboratory.[1]

The contractility of the nerves of plants as well as of animals was another discovery announced by Sir Jagadis Bose a few years ago, which excited my astonishment. But I think the explanation was entirely to be found in the heating effects of the currents used for excitation. A very good object to take for this kind of demonstration is Engelmann's "E" fiddle string, which is certainly non-living matter; upon that one can make all the experiments Sir Jagadis has shown us upon plant nerve contractility and so on. A weak stimulation causes elongation, a strong stimulation causes shortening. If Professor Bose would repeat his experiments in the laboratory we should arrive at a common understanding and a real augmentation of learning. I am taking advantage of the opportunity in the friendliest spirit possible; I am doing it, recognizing that Sir Jagadis is a British citizen of the Indian Section of our Empire, and he comes with a message from which we can well learn. He pointed, in one of his photographs, to the magnificent establishment which he has set up in Calcutta, and looks to it hopefully as a Renaissance of the ancient Indian learning which might be taken by us as an object lesson. We can repeat a statement contained in his dedication of this magnificent Temple of science to

[1] The misgiving to which I gave expression at the meeting, after witnessing the experimental demonstration by Sir J. C. Bose, F.R.S., so far from having been allayed by subsequent proceedings, has been fully confirmed. I could not be sure at the moment whether the movement of the "crescographic" spot to the right indicated growth or not. I am now satisfied that it did not, since it was made upon the upper half of a hyacinth (or daffodil) leaf of which the growth is exclusively basal. Obviously a repetition of the trial on the killed plant could not be made on the spot, but required time and the resources of a laboratory. I placed the resources of the Physiological Laboratory of the University of London at the disposal of the Society and of Sir J. C. Bose in all good faith, and in the expectation that he (or I) might become convinced of his (or my) mistake. My offer was repeated in the *Times*, of March 18, and by Professor Bayliss in the *Times*, of March 30, and accepted by Sir J. C. Bose in the *Times*, of April 3. A demonstration was arranged for by Professor Bayliss, in consultation with Sir J. C. Bose, at the Physiological Institute of University College on April 23. My reiterated requests to be allowed to assist at that demonstration were refused. A report by Professor Bayliss (and of other distinguished professors of University College and of the Imperial College of Science) was published in the *Times*, of May 4, and in *Nature*, May 6. That report is quoted by Sir J. C. Bose as having established his case.

In view of Sir J. C. Bose's confession of faith that he regards it as his duty "to stand up for truth and for freedom of inquiry," I shall still hope that he will not let the matter rest until the correctness of his theory is demonstrated beyond dispute. See also *Journal of Physiology* (Proc. Physiol. Soc.), June 19, 1920.—A. D. W.

his countrymen, including ourselves. He proclaims that it is open to students of all creeds and all nations throughout the Empire and the world. He extends to all students an invitation to come and, by union of mind and sometimes by clash of mind, help in the elucidation of truth. I would like to give, from this side, a cordial acceptance of that invitation, with the invitation that he should lay his head together with us here in London towards that same elucidation. Every laboratory in London is open to him. He has studied here, and is acquainted with our Western methods. It happens sometimes that an Indian comes to us and does things better than we do them ourselves. It happened in the case of cricket, it happens, perhaps, in the case of the physical application of these beautiful instruments which Professor Bose has been showing us at work. I should like to say, as far as the laboratory for which I am responsible is concerned, that I should be delighted to place it at the service of Professor Bose, and if this Royal Society of Medicine wished to invite other experts to examine further into these matters, the resources of the Physiological Laboratory of the University of London are at its full disposal. Therefore, in conclusion, with your permission, I would express, on my own behalf and on behalf of this audience, the gratitude we all feel to Professor Bose for the powerful impetus he has given to the welfare of Science by his foundation of the Bose Institute of Research.

Professor BICKERTON: It only requires, Sir, that someone should second this cordial vote of thanks which has been proposed to the Lecturer, and I have much pleasure in doing so. Having followed Professor Bose's work for a great number of years, I am absolutely delighted with the examples he has shown us to-night. One reads of these researches with a certain amount of interest, but when one sees the experiments in actual operation, it then suggests a series of phenomena which are wonderful. It seems a pity that these discoveries had been virtually suppressed for many years by the papers being relegated to the archives of the Royal Society. The President informs us that the value of Sir Jagadis Bose's work has now become fully recognized as evidenced by his nomination to the Fellowship of the Royal Society; this honour has been long overdue. But when we bear in mind the revolutionary character of Sir Jagadis Bose's discoveries it is no wonder that some time was necessary before his great work received the fullest honour and appreciation. I heartily support the vote of thanks.

The resolution was carried by acclamation.

Sir JAGADIS CHUNDER BOSE (in reply) said: I thank the audience for the warmth of their welcome and the interest evinced in my demonstrations. Dr. Waller spoke in appreciation of the message brought from the East, but it is not in that capacity that I am here this afternoon. I am here to announce and demonstrate new results which may clash with preconceived ideas, and exhibit new methods of experimentation by which phenomena, hitherto in the realm of the invisible, are brought clearly to view. Science knows no geographical boundaries, and the test of truth is the same in the East as in the West. I go further and say that when anyone brings forward facts which challenge existing theories, then the burden of proof must lie with him, and his work ought to be subjected to the closest scrutiny; for without such precaution fact and fancy would become inextricably confused with one another. But criticism must be legitimate; instead of suggesting vague doubts, it must be directed to eliciting definite information in respect to the subject under inquiry. One speaker referred to the difficulties repeatedly experienced by me in publication of my results, till their recent acceptance. My special investigations have by their very nature presented extraordinary difficulties, and these have been greatly aggravated by misunderstanding or misrepresentation. The tide, however, turned, when I was able, six years ago, to bring my apparatus from India and give public demonstrations before the different Universities and Scientific Societies, including the Royal Society of Medicine; and it was a matter of much gratification to me that my work on the establishment of unity of physiological reaction in plants and animals received very cordial appreciation from the late Sir Lauder Brunton and from your Society. The success of my present visit makes me forget the painful incidents of the past, which may now be left to oblivion. I shall now meet the objections raised by Dr. Waller:—

(1) That the enormous magnification employed by me would, according to his calculation, enlarge a blood corpuscle to something like 70 metres in diameter. But if magnification is the objection, then all the great advances of knowledge made by the microscope labour under the same disadvantage.

(2) That the movement shown by my crescograph may not be due to growth, but to physical disturbance, such as that of variation of temperature. With reference to this, my paper on "Researches on Growth and Movement in Plants by means of the High Magnification Crescograph" was, after careful scrutiny by the Committee, accepted by the Royal Society and published last year.[1] In that paper full account is given for eliminating physical disturbance. It is there shown that *the physical elongation due to rise of temperature reaches a maximum, after which the indicator remains in a fixed position; whereas acceleration of growth by rise of temperature, as shown by quicker rate of movement of the indicating spot of light, persists indefinitely.* Dr. Waller has seen that paper, and I am at a loss to understand his omission in the present discussion of so important a part of my communication to the Royal Society. As regards the indications of my crescograph exhibiting induced physiological changes, my audience had the fullest opportunity of watching the enhanced rate of movement of spot of light when the plant was treated with a dose of stimulating drug, a slowing down of the movement being brought about by the action of a depressing agent. Nothing could be more grotesque and misleading than the suggestion that "fiddle strings" exhibited these characteristic physiological reactions.

[1] *Proc. Roy. Soc.*, B, xc, 1919.

(3) A further experiment was shown to decide between the question of physical and physiological action. I have shown how growth-movement becomes retarded by any mode of stimulation, by light, by rough handling, or by electric shock. This retardation has also been shown by me to culminate in an actual contraction under sufficiently strong stimulus; *the movement of elongation due to growth may thus be reversed to an opposite movement of contraction.* This important corroborative experiment was demonstrated before the audience by applying electric shock to the plant, when the normal growth-movement of the spot of light was reversed to the opposite movement to the left. This Dr. Waller regards as merely "de-growth," whatever that may mean. Dr. Waller adduces this as a proof of the dubious character of my demonstration; for according to him *the indicating spot of light should have stopped on the cessation of stimulus*, instead of which the spot of light persisted to exhibit contractile effect by continuing to move to the left. Dr. Waller is in error in supposing that the effect of stimulus on growth lasts during the application. Reference to my Royal Society paper, alluded to above, will show that the after-effect of stimulus, be it electrical, photic or mechanical, persists for a long period.

(4) But the most direct and simple test of discriminating physical from physiological movement would lie in repeating the experiments first with the growing plant, and secondly, with the same plant after it had been killed. If, under similar conditions, the growing plant exhibits movement in the crescograph, and the killed plant no movement, then the inference is clear and obvious that the crescograph does indicate the movement due to growth. Indeed, Dr. Waller himself suggested the desirability of such a test, and when I at once expressed my willingness to repeat this particular experiment, he waived his objection.

As regards the suggestion that my demonstration should be repeated before physiologists, I may say that a very large number of plant and animal physiologists have visited my laboratory and witnessed the experiments. Public demonstrations have also been given before the Universities of Oxford and Cambridge. The President kindly referred to the recognition of the value of my work by the Royal Society nominating me for election to its fellowship. This is a matter of gratification to me as an expression of goodwill and appreciation on the part of my numerous scientific colleagues in this country. And the best return that I can make for this confidence is to stand up for truth and for freedom of inquiry. We are at one both in the East and in the West for the spread of knowledge and for the removal of ignorance. We shall pass away, nations will disappear; Truth alone will survive, for it is beyond the reach of time and is eternal.