an ion with a double positive charge, the CO_3 group an ion with a double negative charge. These ions group themselves in the same way in the calcite and potassium chloride structures, as the models show, except that the form of the CO_3 group distorts the cube into a rhombohedron. The electro-negative atoms of carbon and oxygen hold electrons in common, and form a closely knitted group, and from their distance apart we can form an estimate of the dimensions of the outer electron shell; it is the lower limit to which the diameters tend at the end of each period in Fig. 2.

In this an explanation is found of the large diameters assigned to the electro-positive elements, and the small diameters assigned to the electro-negative elements, in Fig. 2. The electro-positive atoms never share electrons with their neighbours; they are therefore isolated in the crystal structure, and appear to occupy a large domain. The electro-negative elements, bound together by common electrons, have to be represented by small spheres.

Comparing two crystals such as sodium fluoride and magnesium oxide, which have identical structures, we see that both may be represented by alternate electron groups of the Neon type. In the case of magnesium oxide the ions carry a charge twice as great as the sodium and fluorine ions, and the consequence is that the MgO structure, though identical in form with the NaF structure, has its dimensions reduced. The side of the elementary cube has a length of $4{\cdot}22 \times 10^{-8}$ cm. in the case of MgO, a length of $4{\cdot}78 \times 10^{-8}$ cm. in the case of NaF.

In diamond every carbon atom is surrounded symmetrically by four other carbon atoms arranged at the corners of a tetrahedron. The carbon atom has four electrons in its outer shell, and, in order to complete the number eight required for stability, it shares a pair of electrons with each neighbouring atom. The whole crystal is thus one continuous molecule, and the great hardness and density receive a simple explanation.

A crystal of an electro-positive element cannot be bound together by common electrons. Here we must suppose that the crystal consists of ions and electrons, the ions representing the stable electron systems, and the electrons being present in sufficient numbers to make the whole assemblage electrically neutral. From the fact that all crystals of electro-positive elements are conductors of electricity we deduce that the electrons have no fixed place in the system; they move under the influence of an electromotive force.

It has been possible only to indicate the manner in which crystal structure helps to elucidate the structure of the atom, and many generalisations have been made to which there are exceptions. It is hoped that this discussion will show the interest of the study of crystals. In a crystal there are countless atomic groupings oriented with perfect regularity. Individually their effect is too small to observe, but by illuminating the crystal with X-rays, the wave-length of which is much less than the distance separating the atoms, we can make use of their concerted effect on the rays to enable us to see into the intimate structure of matter.

Researches on Growth of Plants.

By SIR JAGADIS CHUNDER BOSE, F.R.S.

II.

The General Principle Determining Tropic Movements.

THE movements in plants under the stimuli of the environment—the twining of tendrils, the effect of temperature variation, the action of light inducing movements sometimes towards and at other times away from the stimulus, the diametrically opposite responses of the shoot and the root to the same stimulus of gravity, the night and day positions of organs of plants—present such diversities that it must have appeared hopeless to endeavour to discover any fundamental reaction applicable in all cases. It has, therefore, been customary to assume different sensibilities especially evolved for the advantage of the plant. But teleological argument and the use of descriptive phrases, like positive and negative tropism, offer no real explanation of the phenomena. I propose to describe experimental results from which it will be possible to discover an underlying law which determines the various tropic movements in plants.

Direct Effect of Stimulus.—In the motile pulvinus of Mimosa the excitation caused by stimulus causes a sudden diminution of turgor and contraction of the cells. With regard to this fall of turgor it is not definitely known whether excitation causes a sudden diminution in the osmotic strength of cell sap or increase in the permeability of the ectoplast. The state of excitation in a vegetable tissue may, however, be detected, as I have shown elsewhere, by the following indications: (1) diminution of turgor; (2) contraction and fall of leaf of Mimosa; (3) electromotive change of galvanometric negativity; (4) variation of electric resistance; and (5) retardation of the rate of growth.

Continuity of Physiological Reaction in Growing and Non-growing Organs.

In investigations on the effect of all modes of stimulation, mechanical, electrical, or radia-

[1] Continued from p. 617.

tional, I find that they check growth or bring about an "incipient" contraction; when the intensity of stimulus is increased, the effect culminates in an actual contraction—a result exactly parallel to the contraction of the pulvinus under direct stimulus. This would explain the similarity of tropic movements in pulvinated and growing organs.

Indirect Effect of Stimulus.—A novel result was discovered under indirect stimulation—that is to say, when the stimulus was applied at some distance from the responding area, *i.e.* the pulvinus or the growing region. This caused an increase of turgor, an expansion, an enhancement of the rate of growth, and an erectile movement of the leaf of Mimosa, and an electromotive variation of galvanometric positivity. This effect is specially exhibited in tissues which are semi-conductors of excitation.[2] The contrasted effects of direct and indirect stimulus are given in the following tabular statement :—

TABLE I.—*Direct and Indirect Effects of Stimulus.*

Direct	Indirect
Diminution of turgor, contraction.	Increase of turgor, expansion.
Fall of leaf of Mimosa.	Erection of the leaf.
Diminution of the rate of growth.	Enhancement of the rate of growth.
Galvanometric negativity.	Galvanometric positivity.

In Fig. 4 is given a record which shows in the same specimen (1) the acceleration of growth under indirect, and (2) a retardation of growth under direct, stimulation.

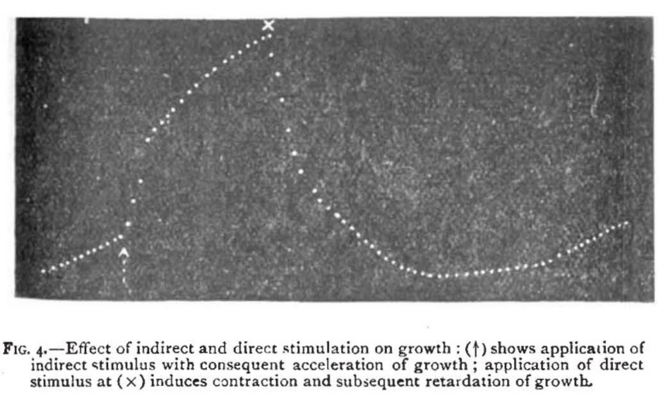

FIG. 4.—Effect of indirect and direct stimulation on growth : (†) shows application of indirect stimulus with consequent acceleration of growth ; application of direct stimulus at (×) induces contraction and subsequent retardation of growth.

We thus arrive at the law of effects of direct and indirect stimulus :—

Direct stimulus induces contraction; indirect stimulus causes the opposite effect of expansion.

The same law applies when stimulus acts on

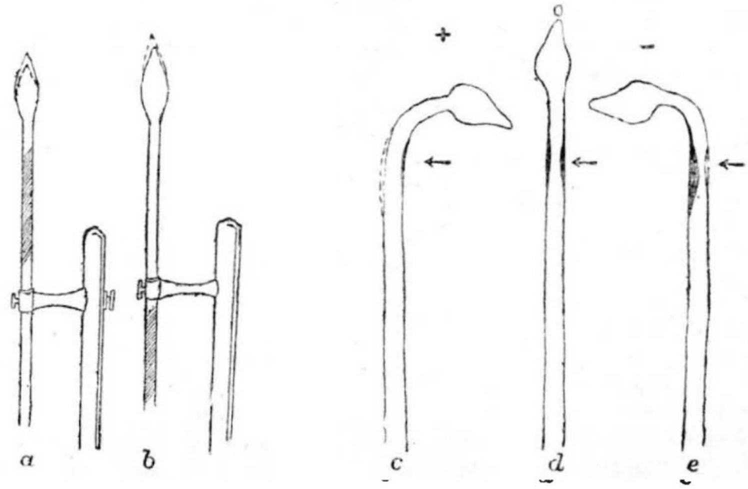

FIG. 5.—Effects of direct and indirect stimulus: *a*, Stimulus applied directly at the growing region inducing retardation of growth or contraction as represented by dotted line (stimulated area in this and in following represented as shaded); *b*, stimulus applied indirectly (at some distance from growing region) gives rise to acceleration of growth and expansion; *c*, stimulus applied at right side of organ causes contraction of that side and expansion of the opposite side, thus giving rise to positive curvature towards stimulus; *d*, excitation transmitted to the opposite side causes neutralisation; *e*, excitation caused by intense stimulation is transmitted across and thus reverses the normal curvature to negative, *i.e.* away from stimulus.

one side of the organ. When stimulus of any kind acts on the right side (Fig. 5*c*) the directly stimulated right side contracts, and the indirectly stimulated opposite, or left side, expands, the result being a *positive* tropic-curvature towards the stimulus. This explains the twining of tendrils and positive heliotropism.

Negative Heliotropism.—When the light is very strong and long continued, the over-excited plant-organs may begin to turn away. How is this effected? My experiments show that the strong excitation percolates into and traverses the organ and provokes contraction on the further side, thus neutralising their former bending (Fig. 5*d*). The organ now places itself at right angles to the light, and this particular reaction has been termed dia-heliotropism. In certain cases the transverse conductivity of the organ is considerable. The result of this is an enhanced excitation and contraction of the further side, while the contraction of the near side is reduced on account of fatigue caused by over-excitation. The organ thus bends away from light or exhibits so-called negative heliotropism (Fig. 5*e*). These effects are accentuated when one side of the organ is more excitable than the other. Thus under the continued action of light the response record shows first a movement towards light, then neutralisation, and finally a movement away from light. In this way a continuity of reaction is demonstrated proving that the assumption of specific positive and negative heliotropic sensibility is unjustified.

That the application of stimulus on the near

[2] "Plant Response," p. 524.

side of the organ induces at first an increase of turgor on the distal side and that this first effect may be neutralised and reversed by transverse conduction of excitation are seen strikingly exhibited in the accompanying record (Fig. 6), where a narrow beam of light was applied at a point of the stem diametrically opposite to the motile leaf which was to serve as the indicator of the induced variation of turgor under the unilateral action of light. That this indirect stimulation caused an enhancement of turgor of the opposite side was soon demonstrated by the erectile movement of the leaf. When the stimulus is moderate and of short duration, the response is only erectile or positive. But when the stimulation is continued the excitatory impulse is conducted to the distal side, giving rise to diminution of turgor, contraction, and the fall of the leaf.

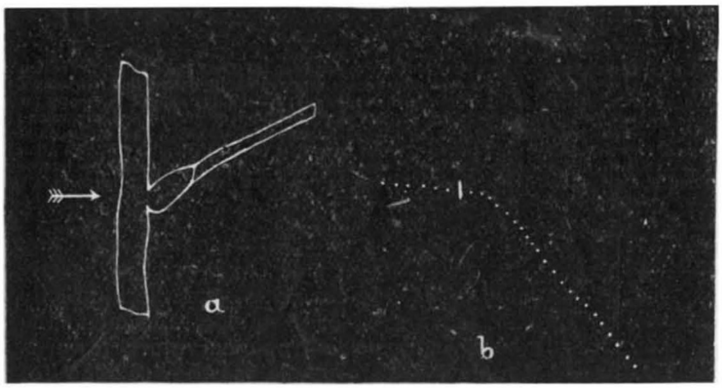

FIG. 6.—Increased turgor due to indirect stimulation inducing erection of Mimosa leaf: *a*, diagram of experiment; *b*, erectile response (shown by down-curve) followed by rapid fall (up-curve) due to transverse conduction of excitation.

TABLE II.—*Showing Responsive Effects Common to Pulvini and Growing Organs under Unilateral Stimulation.*

Effect of direct stimulation on proximal side	Effect of indirect stimulation on distal side
Diminution of turgor.	Increase of turgor.
Contraction and concavity.	Expansion and convexity.
Galvanometric negativity.	Galvanometric positivity.

When stimulus is strong or long-continued, the excitatory effect is conducted to the distal side, neutralising or reversing the first response.

Space does not allow my entering into the question of Nyctitropism, which will be found fully explained in the "Life Movements in Plants," vol. ii.

Geotropism.—No phenomenon of tropic response appears to be so inexplicable as the opposite effects of stimulus of gravity on the root and the shoot. As regards the mechanism of the upcurving of a horizontally laid shoot, it may be due either to the expansion of the lower side or to an active contraction of the other. In order to decide the question I devised the method of geo-electric response whereby the state of excitation (which is attended by contraction) is independently detected by the induced electromotive change of galvanometric negativity. Displacement of the shoot from the vertical to the horizontal position is found to be immediately followed by the clearest electric indication that the upper is the excited side. The electrical response is found to increase as the sine of the angle of inclination. This excitation of the upper side involves its contraction and the resulting geotropic curvature upwards.

Localisation of Geo-perceptive Layer by Means of the Electric Probe.—The new investigation was carried out by means of my electric probe, which consists of an exceedingly fine platinum wire enclosed in a capillary glass tube, the probe being 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 deflection shows by its indication the state of irritation of every layer of cells throughout the organ. When the stem is held in a vertical position the probe during its passage shows little or no electric sign of irritation. But when the stem is displaced from the vertical to the horizontal position, the geotropically sensitive layer now perceives the stimulus and becomes the focus of irritation, and the probe on reaching this point gives the maximum deflection of galvanometric negativity. This electric indication of irritation disappears as soon as the geotropic stimulus is removed by restoration of the stem to a vertical position. I was thus able to map out the contour lines of physiological excitation inside a living organ. The geo-perceptive layer was thus localised at the endodermis.

In geotropic response the only anomaly that remained was in regard to the response of the root being opposite to that of the shoot. Every cut portion of the growing region of the shoot responds to the stimulus of gravity by bending upwards. The growing region of the shoot is therefore both sensitive to stimulus and responsive to it. *Hence geotropic stimulation of the shoot is direct.* But this is not the case with the root; here it is the tip of the root which perceives the stimulus, the geotropic bending taking place at some distance from the tip. From the results of electric investigation I find that the root tip becomes directly stimulated, while the responding growing region some distance from it becomes indirectly stimulated. *Hence geotropic stimulus acts indirectly in the responding region of the root.* I have shown that the effects of direct and indirect stimulus on growth are antithetic; it therefore follows that the responses of shoot and root to the direct and indirect stimulus must be of opposite signs.

The diverse movements of plants are thus explained from the establishment of the general law that direct stimulus induces a contraction and indirect stimulus an expansion.

I have shown, further, the extraordinary similarity of physiological reaction in the plant and animal (Friday evening discourse, Royal Institution, May 29, 1914). The responsive phenomena in plants must thus form an integral part of various problems relating to irritability of all living tissues, and without such study the investigation must in future remain incomplete.

Popular Natural History.[1]

(1) THE best popularisers, after all, are the masters—if they care to try; and Fabre's "Story Book of Science" is a fine illustration. It is very perfect—full of interesting material, vividly written, stimulating both observation and reflection. He tells of ants, aphides, long-lived plants and animals, procession caterpillars, bees, spiders, shells, cotton, paper, silk, clouds, thunder, rain, the sea, and more besides—all as if it were a pleasure to him to talk, and just the very easiest thing in the world. The book must have been fashioned long ago, but so wisely that there is little that requires changing; it was meant for the children of more than a generation ago, and it would be a joy of a reading-book in schools to-day; it was written in French, and it reads as if it had been composed in English. The translator, Mr. A. T. De Mattos, has done his work with great skill. We confess that we should not call Hemerobius a dragon-fly, and there must be something wrong in speaking of the "sharp bones" in the silk-moth's cornea, which Fabre described as a rasper for filing at the silk threads of the cocoon. But these are pin-pricks; the book is past praising, and its pages are very pleasant to read—pleasant both to the inner and the outer eye. We should be having a Fabre centenary soon.

(2) A translation of Fabre's "Story Book of Birds and Beasts" is very welcome. The subjects are for the most part familiar, but the handling of them is masterly in its simplicity, grip, and vividness. Fabre had a way of taking the reader into his confidence, and making a sort of partner of him in his observations. But it is a game that only a big man can play with success. We are introduced to the cock and the hen, the egg and the chicken, the duck and the goose and the pigeon, the cat and the dog, the sheep and the cow, the horse and the donkey, and we get interested in them as if they were novelties. It is high art. The stories should be used in schools.

The book is not without blemishes, of which we venture to give some samples. We do not know what to call the first part of a hen's stomach, but we are sure that it cannot be called "the succenturiate ventricle." The story of the making of the shell of the egg is misleading, and it is not true to say that the hen *must* have carbonate of lime in her food. We are rather staggered by some humming-birds "as small as our large wasps." The account given of "pigeon's milk" is erroneous. It should have been noted that the passenger pigeon, in regard to which Audubon's account is quoted, has now ceased to exist. For the translator's work we have great admiration; but it might have shown wisdom as well as piety to have got an editorial expert to look into points such as we have illustrated. There is no sense in perpetuating mistakes.

(3) Dr. Francis Ward's book is in great part an attempt to take the point of view of the animal under water.

> Seen from below, the surface of the water would appear as an extensive mirror, with the river-bed reflected upon it. Immediately above the observer the reflecting surface is broken by a circular hole or "window." Through the surface of the water, in the area of this "window," the sky and objects immediately overhead have their usual appearance, but in addition surrounding objects above the water level are also seen through the "window" as dwarfed and distorted images, suspended, as it were, in the air above the circumference of the circular hole. A ring of iridescent colours separates the "window" from the surrounding reflecting surface.

Many of Dr. Ward's observations have a direct bearing on the concealment of aquatic animals, and deserve careful attention from naturalists. Let us illustrate. The size of the "window" varies with the depth of the under-water observer; when birds and fishes on the surface slip out of the "window" they cease to be conspicuous (to their enemies below) as silhouettes against the sky. Protection under water may be afforded, as in the case of brown trout, by reflection of the surrounding coloration. White animals, such as a white sea-anemone, take up a position where the revealing top light is cut off. Black-plumaged birds, like the water-hen, become mirrors under the water owing to reflection from the air-bubbles retained in their plumage.

After explaining the sub-aquatic conditions as

[1] (1) "The Story Book of Science." By J. H. Fabre. Pp. 299. (London: Hodder and Stoughton, n.d.) Price 7s. 6d. net.
(2) "The Story Book of Birds and Beasts." By J. H. Fabre. Pp. 315. (London: Hodder and Stoughton, n.d.) Price 7s. 6d. net.
(3) "Animal Life under Water." By Dr. Francis Ward. Pp. x+178+plates. (London: Cassell and Co., Ltd., 1919.) Price 7s. 6d. net.
(4) "Birds in Town and Village." By W. H. Hudson. Pp. ix+274. Illustrated. (London and Toronto: J. M. Dent and Sons, Ltd.; New York: E. P. Dutton and Co., 1919.) Price 10s. 6d. net.
(5) "The Book of a Naturalist." By W. H. Hudson. Pp. viii+360. (London: Hodder and Stoughton, n.d.) Price 12s. net.
(6) "Wonders of Insect Life: Details of the Habits and Structure of Insects." Illustrated by the Camera and the Microscope. By J. H. Crabtree. Pp. viii+211+32 plates. (London: George Routledge and Sons, Ltd.; New York: E. P. Dutton and Co., n.d.) Price 6s. net.
(7) "Just Look! or, How the Children Studied Nature." By L. Beatrice Thompson. Pp. viii+204+58 plates. (London: Gay and Hancock, Ltd., n.d.) Price 5s. net.