

water-transformations much more important than those on our globe. There are also papers on Venus and her satellite, the tides in the Mediterranean, the heavens in August, &c.

A CURIOUS and little-known experiment, showing the resistance of the air in guns, is described by Prof. Daniel Colladon, of Geneva, in a recent letter to M. Melsens (*Bull. Belg. Acad.* No. 6). He was long in the habit of showing it to his classes. It resembles a feat that was sometimes performed by soldiers with the old Swiss carbines. M. Colladon fully charged with compressed air the hollow iron breech of an air-gun, serving as reservoir. Having screwed up the gun, he introduced a round lead ball, running freely, but nearly filling the bore; then, placing the gun vertical, he seized the upper end and pressed his thumb vigorously on the mouth. The gun was then "fired" by an assistant; the thumb remained in position, and the ball was heard to fall back in the bore. Thereupon, after recharging the breech and with the same ball, he shot the latter at a pine board about 4 in. thick, or a pane of glass, and it passed through. The experiment, M. Colladon says, is without danger, if the operator is sure of the strength of his thumb, if the gun is more than 32 in. long, and if the ball is spherical and nearly fills the gun (in which it must act like a piston). The least uncertainty in the very vigorous pressure of the thumb, and hermetic closure of the gun, may entail serious injury to the thumb. While M. Colladon has repeated the experiment twenty or thirty times, without the least inconvenience either from shock or heat, a trial of it is perhaps hardly to be recommended.

THE additions to the Zoological Society's Gardens during the past week include a Common Raccoon (*Procyon lotor*) from North America, presented by Mr. Mark Vice; a Passerine Owl (*Glaucidium passerinum*), European, presented by Miss Maud Howard; six Common Guillemots (*Uria troile*), European, presented by Sir Hugh Dalrymple, Bart.; an Allen's Porphyrio (*Porphyrio alleni*), captured at sea, presented by Master J. Kennedy; forty Restless Cavies (*Cavia caprera*), British, presented by H.R.H. the Prince of Wales, K.G.; a Four-rayed Snake (*Elaphis quateradiatus*), South European, presented by Capt. Adams; a Smooth Snake (*Coronella levis*), British, presented by Mr. W. Penney; an Egyptian Cobra (*Naia haje*) from South Africa, presented by Mr. Eustace Pillans; a Common Viper (*Vipera berus*), British, presented by Mr. H. J. Benwell; a Lesser White-nosed Monkey (*Cercopithecus petaurista*) from West Africa, a Grey Ichneumon (*Herpestes griseus*) from India, a Goffin's Cockatoo (*Cacatua goffini*) from Queensland, a White-headed Sea Eagle (*Haliaeetus leucocephalus*) from North America, a Chequered Elaps (*Elaps lemniscatus*) from Brazil, deposited; three Black Lemurs (*Lemur macaco* ♂ ♂ ♀), a White-fronted Lemur (*Lemur albifrons* ♂) a Red-fronted Lemur (*Lemur rufifrons* ♂) from Madagascar, a Cape Hyrax (*Hyrax capensis*) from South Africa, a Westerman's Cassowary (*Casuarus westermanni*) from New Guinea, two Pileated Jays (*Cyanocorax pileatus*) from La Plata, two White-faced Tree Ducks (*Dendrocygna viduata*), two Rufous Tinamous (*Rhynchotus rufescens*) from Brazil, two Tataupa Tinamous (*Crypturus tataupa*) from South America, an Argentine Tortoise (*Testudo argentina*) from the Argentine Republic, two Common Chameleons (*Chamaeleon vulgaris*) from North Africa, two Aldrovandi's Lizards (*Plestiodon auratus*) from North-West Africa, purchased; two Mocassin Snakes (*Tropidonotus fasciatus*), born in the Gardens.

THE EXCITABILITY OF PLANTS¹

IT will be in the recollection of many who are present this evening that in February of last year I had the honour of delivering a Friday evening discourse on a subject which included that which has been announced for to-night. In that lecture I

¹ Lecture delivered at the Royal Institution June 9, 1882, by Prof. Burdon Sanderson, F.R.S.

had hoped to present to you a comprehensive view of the excitatory motions both of plants and of animals; that is, of those motions which they perform in response to transitory impressions received by them from outside. I was desirous that the statements that I made to you with reference to animal excitability should be as fully as possible illustrated by experiments, in the carrying out of which much more time was lost than I had reckoned for; so that I was unable even to enter on the second part of my subject. The time at my disposal will not permit me to summarise my last lecture, however advantageous it might be to do so. I must content myself with recalling your attention to one or two fundamental points.

Under the term excitability are comprised all cases in which some definite change in the behaviour of a living structure, whether it be a whole animal or a part, constantly arises as the result of some transitory external influence. But for the purpose in view, those cases only were included (typical of the rest) in which some sort of muscular motion is performed in response to an excitation or stimulus. The effect of such excitation we call the excitatory process, and we say, as the result of observation, that it consists of two phases or stages—namely, the phase of latency, and the phase of visible effect. These were illustrated in the last lecture by a series of experiments in which the excitable tissue of the heart of the frog was used. It was first shown with reference to this tissue that when it is touched (that is excited) with the tip of a glass rod, it undergoes a definite change of form, at the same time doing mechanical work at the expense of material contained in, but not forming part of, its own substance; secondly, that this mechanical effect did not begin until the lapse of an easily measurable period after the excitation; it was then pointed out that the interval of time between the prick and the visible or mechanical effect—the change of form, or contraction of the contractile substance—was one during which, though no visible change occurred in the excited part, molecular changes must certainly be in progress, and that these were accompanied by electrical disturbance.

To illustrate this, I demonstrated to you that the electrical change which in all cases accompanies excitation, precedes the mechanical one in time. You will remember that by means of the electric light the outline of the muscle to be excited and the image of the galvanometer mirror were projected on the screen, and that we were able to observe that when the muscle was pricked, the electrical disturbance had time to produce a deflection of the magnet which was visible on the screen before the muscle contracted.

It was further shown that an excitatory effect analogous to that which in muscle constitutes the first phase is produced in nerve, that in both the process of excitation is capable of being propagated in the same sort of way that an explosion is propagated in a train of gunpowder, and, finally, that the existence in nerve of this endowment is the instrumentality by which, in the human body, the will is able to influence and govern all the rest, and to receive influences from outside.

To-night we shall occupy ourselves exclusively with plants. I shall endeavour to show not only that they possess the wonderful property of excitability by which one part is able to influence another part at a distance, but that there is reason for believing that the excitability they possess is essentially of the same nature as that of animal tissue. And now, without further preface, I propose to enter on my subject by first giving you a short account of some of the most instructive instances of excitable plants.

The number of plants which exhibit what is often called irritability is very considerable. I will not weary you with even enumerating them. You will see from the table that they are distributed among a number of natural orders, so that one might be inclined to suppose that in this respect no relation could be traced between the physiological endowments and the morphological characters of a plant. That it is not so we have abundant evidence. Thus in the same genus we may find all the species excitable, though not in the same degree. The extreme sensitiveness of the Chinese Oxalis, formerly called *Biophytum sensitivum*, because it was supposed to be particularly alive, appears in a less degree, but equally distinctly in our own wood sorrel, as well as in the Tree Oxalis of Bengal—the *Carambola*,¹ which is described in an interesting letter addressed by Dr. Robert Bruce to Sir Jos. Banks, and published in the Philosophical Transactions. Again, in the same order, as, for example, among composite plants, we may have the Thistles, Knap-

¹ An account of the sensitive quality of the tree *Averrhoa Carambola*. By Robert Bruce, M.D. *Phil. Trans.*, vol. lxxv. p. 356

weeds, and Hawkweeds, all showing excito-contractility in the same way, although the plants do not at all resemble each other in external appearance. In order to make you acquainted with the mechanism by which the excitable motions of plants are brought about, I will confine myself to a very few examples, selecting, of course, those which have been most carefully investigated.

Every one is acquainted with the general aspect of the sensitive plant. Probably, also, most persons have observed the way in which the leaves behave when one of them is touched, namely, that the leaf, instead of being directed upwards, suddenly falls, as if it had lost its power of supporting itself, and that the little leaflets which spring from the side stalks fold together upwards (Fig. 1). But perhaps every one has not observed exactly how this motion is accomplished, namely, that by means of little cylindrical organs the leaflets are jointed on to side-stalks, the side-stalk on to the principal stalk, and the principal stalk on to the stem. In those little cylinders, the powers of motion of the leaf have their seat. They may, therefore, be called the motor organs of Mimosa. I would ask your attention to their structure.

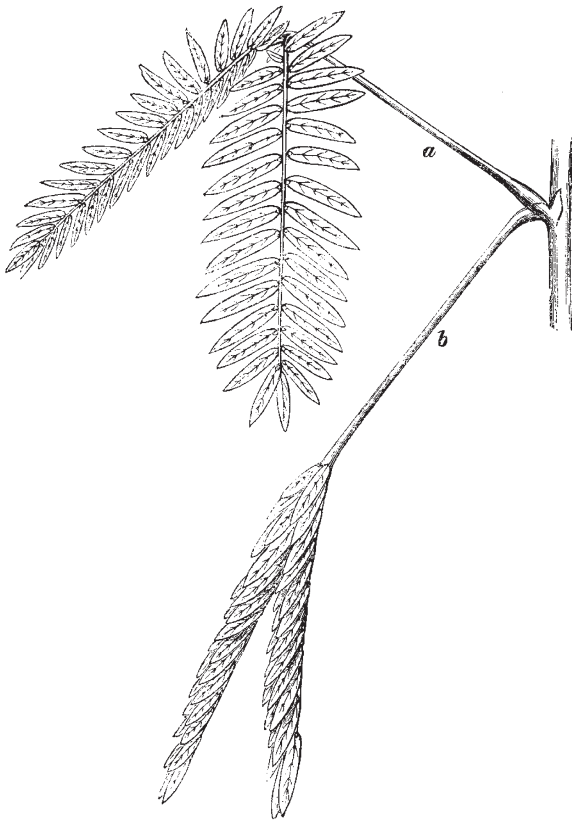


FIG. 1.—Leaf of Mimosa; *a*, in the unexcited state; *b*, after excitation (after Pfeffer).

In my description I will confine myself to the relatively large joint at the base of the principal leaf-stalk. If you make a section through it in the direction of its length, you find that it consists of the following parts. In the axis of the cylinder is a fibro-vascular bundle; above it are numerous layers of roundish cells with thick walls, and between these there exist everywhere intercellular spaces, which in the resting—that is the excitable—state of the organ, are filled with air. The surface is covered by epidermis. Below the axial bundle there are equally numerous layers of cells, but they differ from them in this respect, that their walls are more delicate (Fig. 2). And now let us study the mechanism of the motion. The literature of this subject is voluminous. Substantially, however, we owe the knowledge we possess to two observers—E. Brücke, ¹who studied it in 1848,

¹ Brücke, "Ueber die Bewegung der Mimosa pudica." Müller's "Archiv," 1848, p. 434.

and Pfeffer,¹ whose work appeared in 1873. I must content myself with the most rapid summary.

Let me begin by noticing that Mimosa, in common with many other excitable plants, exhibits that remarkable phenomenon which we commonly call the sleep of plants, that is, that as night approaches the leaf-stalks sink, and the leaflets fold up, the whole leaf assuming a position closely resembling that which it assumes when it is irritated. All that time will allow me to say on this subject is that although the leaf assumes the same position in sleep as after excitation, the two effects are not identical. The state of sleep differs from that in which the plant finds itself after it has been irritated in two particulars. The first is, that in the state of sleep it is still excitable, and responds to stimulation exactly in the same way, although from being already depressed the extent of its motion is diminished; the other is, that in sleep, the joint, although bent downwards, is still more or less resistant and elastic; whereas in the unexcitable (or, what comes to the same thing *excited*) state, all elasticity has disappeared. In a word, in the motor organ of Mimosa, in common with all other excitable structures, the characteristic of the excited state is *limpness*. All the Mimosa plants on the table are in the state of sleep, but are still excitable, for when they are touched they sink to an even lower position than that of sleep, and at the same time become limp. Hence you have, as the result of excitation, two changes, namely (1), the change of position, only to be observed when the plant is awake, and (2) the loss of stiffness, dependent, as we shall see, on a vital change in the protoplasm of the cells, which is also observed when the plant is asleep.

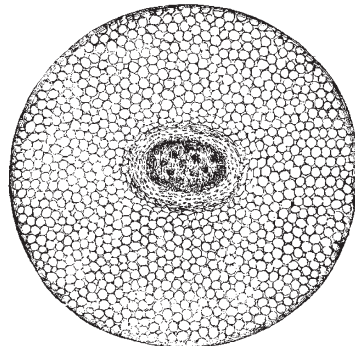


FIG. 2.—Section of the motor organ as projected on the screen. The vascular bundle in the middle of the section consists of a cylinder of thick-walled woody fibres and vessels, surrounded by a layer (annular in section) of elongated cells. The parenchyma is thicker below than above the vascular bundle. The section fails to show that the walls of the cells of the upper half have thicker walls.

So much for the general nature of the excitatory change. How do we discover what the mechanism is by which this remarkable organ of motion acts? By a mode of experiment which is well known to the physiologist. It may be called the method of ablation. We have here a mechanism which consists of several distinct parts, each, we may presume, having a distinct purpose; and the only method which will enable us to discover what these several purposes are is to observe how each acts alone—or, on the other hand, how the rest act after it has been taken away.

To prove that the motion of the whole leaf is dependent on the motor organ at the base of its stalk, requires no experiment. We see that the leaf descends, the joint bends, while the stalk remains rigid, and we know from its structure that the latter contains no mechanism by which it can act mechanically on the joint, as I act on my wrist by the muscles of my fore-arm.

The question therefore is—What part of the joint is essential? We begin by taking away the upper half, leaving the axial bundle and the lower half, and find that the leaf assumes a higher position than before. When touched, it falls. The function of the upper part, therefore, is merely auxiliary. The essential part is the lower, which in the unexcited state is capable of bearing the weight of the leaf. When it is excited it suddenly becomes weak, and the leaf falls. How does it do this? We will proceed to remove the axial bundle. The cellular cushion expands and lengthens, showing that it is elastic, and has a tendency to spring out when liberated. We have seen that this resistant cushion consists of cells, that is, of li

¹ Pfeffer, "Physiologische Untersuchungen," p. 9.

bladders, each of which is distended with liquid. And its tendency to expand as a whole is due to the tendency to expand of the innumerable cells of which it is made up. In the unutilated state these are squeezed into a smaller space than that which they would assume if they were left to themselves; and, consequently, as their expansion is prevented, or curbed on one side, it acts on the opposite side, so as to bend the cylinder in the direction of the restraint.

All of this we can, perhaps, better understand by a model; and it is possible to make one which, not only in form but in principle, corresponds to the living mechanism it is intended to illustrate. In the model the axial bundle is represented by a strip of leather, the innumerable cells of the excitable cushion by an india-rubber bag. By a pump we are able to fill this cell or cushion more or less with fluid, and thus to vary its tension, and you see that if we increase the tension, the stem rises. By diminution it suddenly falls, just as the Mimosa leaf does when irritated.

We have come then to this point—that the reason why the leaf suddenly sinks on excitation is that the cells undergo a sudden diminution of tension or expansion. But our inquiry is not yet terminated. We have still to ask, How is this loss of tension effected? The answer is, by discharge of water. In the unexcited state all these cells are distended or charged with liquid. Suddenly, when the structure is excited, they let out or discharge that liquid, and it finds its way first into the intercellular air spaces, and secondly, out of the motor organ altogether. This we know to be a fact by an experiment of Pfeffer's, which must be regarded as one of the most important relating to the mechanism of plants that was ever made. He observed that if the leaf stalk is cut off from the motor organ, a drop of fluid appears at the cut surface at the moment that the latter bends downwards on excitation, and that in the experiment described just now, in which the upper part of the motor organ is cut off, there is also, so to speak, a sweating of liquid from the cut surface.

We are therefore certain that liquid escapes, but why does it escape? That I shall explain further on, and will now proceed to two other examples. One is a plant which is a great favourite in London, for it is one which flourishes even in London smoke—*Mimulus*. For our purpose it is good chiefly because its structure is very simple. It is one of those examples in which excitability is associated with the function of fertilisation, and inasmuch as this is a very transitory purpose, the property itself is transitory. When the cells of the stigmatic surface are touched they discharge their liquid contents, and consequently become limp. The outer layer of the lip is elastic, and tends to bend inwards. Consequently when the inner cells lose their elastic resilience it is able to act, and the lip bends inwards. In another allied plant, *Goldfussia anisophylla* (Fig. 3), which was described forty years ago by the Belgian naturalist Morren, we have the same mechanism. In this plant, as shown in the drawing, the style is not lipped but awl-shaped. It reaches to the mouth of the showy, orange-coloured corolla, to the inside of which it is united by its under surface. It has a smooth side, the epidermis of which is made up of numerous small prismatic cells, and is very elastic, and in the unexcited state concave, and a papillated side beset with the nipple-like ends of cylindrical cells, which, when unexcited, are distended with liquid. These cylindrical cells are continuous with those of the conducting tissue of the style. When an insect enters the flower, it does two things: it charges the fringe of hairs on the inside of the corolla with pollen, and touches the style, which, in consequence, bends suddenly in the opposite direction to that in which it was bent before, so as to plunge its stigmatic surface into the fringe. In this motion the epidermis acts as a spring simply. So long as the stigmatic tissue is turgid it cannot act. The moment its cells lose their tension, off it goes.¹

Another plant investigated by Morren is one of very different organisation, but is one in which the existence of excitability has an equally plain teleological interpretation. Long ago Robert Brown, to whom plant-lore owes so much, when exploring the flora of Botany Bay, became acquainted with the now well-known Australian plant called *Stylidium*.² [A specimen from the Royal Gardens at Kew was exhibited.] Here is the plant (Fig. 4). The flower is too small to be easily seen, but the diagram will enable you to understand the mechanism. It has

¹ "Recherches sur le mouvement, &c., du style du *Goldfussia anisophylla*." *Mém. de l'Acad. Royale de Bruxelles*. 1839, vol. xii.
² Morren, "Recherches sur le mouvement et l'anatomie du *Stylidium gaminifolium*." *Mém. de l'Acad. de Bruxelles*, t. xi., 1838.

again to do with insects and fertilisation. In *Stylidium* the anthers and stigma are united together at the summit of a cylindrical stem which may be compared with the motor organ of *Mimulus*. You might naturally suppose that they were arranged so in order that the pollen from these anthers should be at once received by the adjoining stigmatic surface. That it is not so is evident from the order of development of the flower, for you find that at the moment that the anthers burst the stigma is not yet mature. Consequently the pollen is not intended for it, but for flowers which have come to maturity earlier, and the mechanism which now interests us fulfils this purpose. The figure shows the singular form of this strange flower. You observe that the column, as it is called, is bent down over the

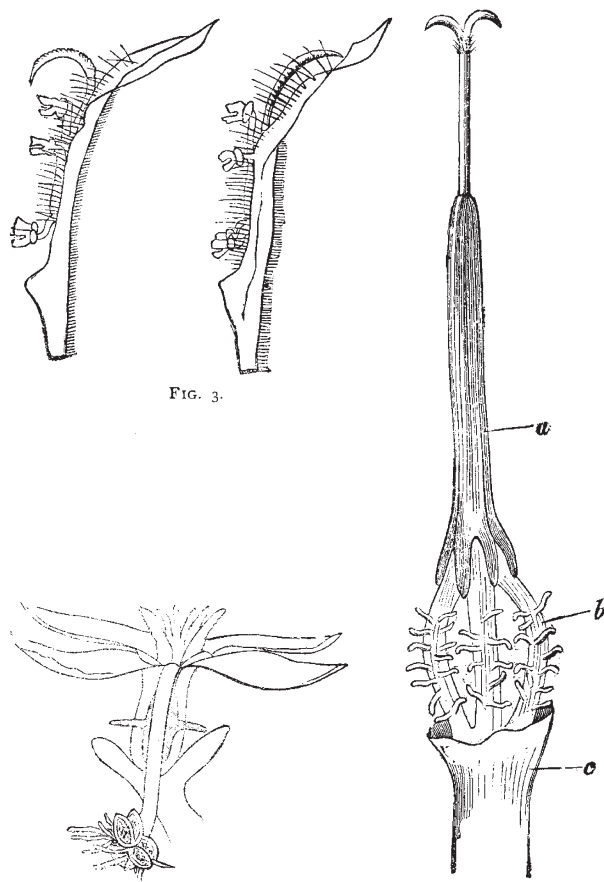


FIG. 3.

FIG. 4.

FIG. 5.

FIG. 3.—Style, stamens, and part of corolla of *Goldfussia*. In the left-hand figure the style is in the unexcited state, and is curved upwards, so that the stigmatic surface looks towards the mouth of the corolla. On excitation it suddenly assumes the position shown in the second figure, the stigma looking towards the roots of the collecting hairs.

FIG. 4.—Flower of *Stylidium*, showing the column in the unexcited state, terminating in the anthers and stigma, which are surrounded by conspicuous hairs. It is bent down at the mouth of the corolla, the four principal lobes of which are seen, two on each side, and partly conceals the fifth lobe or labellum.

FIG. 5.—A floret of *Centaurea* as prepared for projection on the screen. The corolla (c) has been cut away so as to expose the five filaments (f), beset with hairs, and united above into the anther tube (a). The filaments are arched outwards, as in the unexcited state.

corolla so as to be in contact with the odd-looking labellum, which here takes the place of one of the petals. At the moment that the anthers burst the column attains its greatest sensitiveness. The slightest touch causes it to spring up, straighten itself suddenly, and then bend over to the opposite side. The mechanism resembles that of *Mimosa* and of *Mimulus*. There is a spring, the action of which is restrained by the resilience of cells distended with liquid. Suddenly these cells discharge their contents, and the spring acts.

And now let me pass to another group of plants which may serve as a contrast to *Stylidium*. *Stylidium* may be called an

out-of-the-way plant. It has an organisation which is not represented in the European flora. The family of thistles, and their allies the knapweeds (represented in our gardens by the ladies blue bottle), all of which are common wayside plants, exhibit excitable movements which, although of a very different kind from those we have just described, have, like them, to do with the visits of insects for the purpose of fertilisation. We will now throw on the screen a single fertile floret of *Centaurea Cyanus* (Fig. 5). The large diagram shows the same floret deprived of its corolla. Its axis is occupied by the style, surrounded by its tube of anthers. Below, the anther-filaments expand into a kind of cage, and again approach one another, when they are united with the tube of the corolla. At the moment that the anthers arrive at maturity these filaments are very excitable. When one of them is touched, it contracts and draws the style towards itself. Immediately afterwards the excitatory effect spreads to the others, all five arches becoming straight, and applying themselves closely to the style. A similar effect is produced by an induction shock. [The structure described was projected on the screen; on passing an induction current through it, the mode of contraction of the filaments was seen.]

The mechanism of *Centaurea* has been studied by many plant physiologists, particularly by Prof. Ferdinand Cohn of Breslau, and more recently with great completeness by Prof. Pfeffer. It has in this respect a greater interest than any other—that the shortening of these filaments in response to excitation strikingly resembles muscular contraction. You have here a structure in the form of a flattened cylinder which resembles many muscles in form, the length of which is diminished by about a sixth on excitation. This superficial resemblance between the two actions makes it the more easy to appreciate the differences.

Let me draw your attention to the diagram of an experiment made last year, which was intended to illustrate the nature of muscular contraction, and particularly to show that when a muscle contracts, it does not diminish in volume. The first difference between muscle and plant is a difference in the degree of shortening. A muscle shortens by something like a third of its length, the anther filament only by a sixth. But it is much more important to notice that in contracting, the filaments do not retain their volume. In shortening they broaden, but the broadening is scarcely measurable; hence they must necessarily diminish in bulk, and this shrinkage takes place, as Pfeffer has shown, exactly in the same manner as that in which the excitable cushion of *Mimosa* shrinks, namely by the discharge of liquid from its cells.

We are now in a position to study more closely the question to which I referred a few minutes ago—How do the cells discharge their contents? The structure of the filament of *Centaurea*, from its extreme simplicity, is a better subject of investigation with reference to this question, than any other. Each filament is a ribbon consisting of (1) a single fibre-vascular bundle, (2) delicate cells of regular cylindrical form, (3) an epidermis of somewhat thick-walled cells. [Microscopical preparations were shown.] In *Mimosa* we saw that the epidermis and vascular bundle took only a passive part in the production of the motion. Here, the part they play is even less important. Everything depends on the parenchyma, which, when excited, shrinks by discharging its water. Pfeffer proved this by cutting off the anther tube from the filaments, and then observing that on excitation a drop collected on the cut surface, which was reabsorbed as the filament again became arched. It is obvious that if the whole parenchyma discharges its liquid, each cell must do the same, for it is made up entirely of cells. To understand how each cell acts, we have only to consider its structure. Each consists of two parts—an external sac or vesicle, which is of cellulose, and, so long as the cell is in the natural or unexcited state, *over-distended*, so that, by virtue of its elasticity, it presses on the contents with considerable force; and secondly, of an internal more actively living membrane of protoplasm, of which the mechanical function is, so long as it is in its active condition, to charge itself fuller and fuller with liquid—the limit to further distension being the elastic envelope in which it is inclosed. In this way the two (the elastic envelope and the protoplasmic lining) are constantly in antagonism, the tendency of the former being towards discharge, that of the latter towards charge. This being so, our explanation of the effect of excitation on the individual cell amounts to this—that the envelope undergoes no change whatever, but that the protoplasm suddenly loses its water-absorbing power, so that the elastic force of the envelope at once comes into play and squeezes out the cell-contents. Consequently, although here, as everywhere, the

protoplasm is the seat of the primary change, the mechanical agent of the motion is not the protoplasm, but the elastic envelope in which it is inclosed.

(To be continued.)

ELECTRIC LIGHTING BY INCANDESCENCE¹

SPEAKING in this place on electric light, I can neither forget nor forbear to mention, as inseparably associated with the subject and with the Royal Institution, the familiar, illustrious, names of Davy and Faraday. It was in connection with this institution that, eighty years ago, the first electric light experiments were made by Davy, and it was also in connection with this Institution that, forty years later, the foundations of the methods, by means of which electric lighting has been made useful, were strongly laid by Faraday.

I do not propose to describe at any length the method of Davy, I must, however, describe it slightly, if only to make clear the difference between it and the newer method which I wish more particularly to bring under your notice.

The method of Davy consists, as almost all of you know, in producing electrically a stream of white-hot gas between two pieces of carbon.

When electric light is produced in this manner, the conditions which surround the process are such as render it impossible to obtain a small light with proportionally small expenditure of power. In order to sustain the arc in a state approaching stability, a high electromotive force and a strong current are necessary; in fact, such electromotive force and such current as correspond to the production of a luminous centre of at least several hundred candle-power. When an attempt is made to produce a smaller centre of light by the employment of a proportionally small amount of electrical energy, the mechanical difficulties of maintaining a stable arc, and the diminution in the amount of light (far beyond the diminished power employed), puts a stop to reduction at a point at which much too large a light is produced for common purposes.

The often-repeated question, "Will electricity supersede gas?" could be promptly answered if we were confined to this method of producing electric light; and for the simple reason that it is impossible, by this method, to produce individual lights of moderate power.

The electric arc does very well for street lighting, as you all know from what is to be seen in the City. It also does very well for the illumination of such large inclosed spaces as railway stations; but it is totally unsuited for domestic lighting, and for nine-tenths of the other purposes for which artificial light is required. If electricity is to compete successfully with gas in the general field of artificial lighting, it is necessary to find some other means of obtaining light through its agency than that with which we have hitherto been familiar. Our hope centres in the method—I will not say, the *new* method—but the method which until within the last few years has not been applied with entire success, but which, within a recent period, has been rendered perfectly practicable—I mean the method of producing light by *electrical incandescence*.

The fate of electricity as an agent for the production of artificial light in substitution for gas, depends greatly on the success or non-success of this method; for it is the only one yet discovered which adapts itself with anything like completeness to all the purposes for which artificial lighting is required.

If we are able to produce light *economically* through the medium of *electrical incandescence*, in small quantities, or in large quantities, as it may be required, and at a cost not exceeding the cost of the same amount of gas-light, then there can be little doubt—there can, I think, be *no* doubt—that in such a form, electric light has a great future before it. I propose, therefore, to explain the principle of this method of *lighting by incandescence* to show *how it can be applied*, and to discuss the question of *its cost*.

When an electrical current traverses a conducting wire, a certain amount of *resistance* is opposed to the passage of the current. One of the effects of this conflict of forces is the development of heat. The amount of heat so developed depends on the nature of the wire—on its length and thickness, and on the strength of the current which it carries. If the wire be thin and the current strong, the heat developed in it may be so great as to raise it to a white heat.

¹ Lecture delivered at the Royal Institution of Great Britain, March 10, 1882, by Joseph W. Swan, Sir Frederick Bramwell, F.R.S., vice-president, in the chair.