THE PHYSIOLOGICAL ACTION OF LIGHT[1]

NEW Method of Experimenting.—One of the chief difficulties in arriving at the exact relation between the electrical variation and the luminous and colour intensity of light, was the continually diminishing sensibility to the stimulus, owing to the abnormal conditions of the eye when removed from the head. When the experiment begins, the eye is remarkably sensitive to light, and a large variation of current is obtained; but the amount of this current is gradually falling, in consequence of the gradual change in the parts of the eye, owing to their loss of vitality and sensibility. In fact, the parts are dying—the blood is not circulating, and molecular and chemical changes are slowly occurring. In the case of the frog however, it is a fact that the retina retains its sensibility from three to four hours, and sometimes longer. After a lapse of two hours the frog's eye frequently remains in a tolerably stable condition, in which it does not lose sensibility rapidly. This condition may last for four

Diagram showing arrangement of apparatus in the experiment on eye o frog A, Eye showing the electrode, E, in contact with it. B, Skin removed, and subcutaneous tissue in contact with other electrode, E. K, Key. G, Galvanometer. Arrows indicate direction of current. Cornea, positive. Back, negative.

or five hours. In order to get rid of the difficulty of gradual death of the parts, various methods were tried in earlier experiments in the attempt to remove the eye as quickly as possible, and to make the observations rapidly. In the case of the warm-blooded animals this did not lead to good results, because the sensibility to light disappeared in a very few minutes. On several occasions the posterior aspect of the eye was exposed in the living anæsthetised warm-blooded animal, and on bringing one electrode into contact with the severed optic nerve while the other touched the cornea, the observations were tolerably constant. This method was troublesome and difficult.

These experiments are now made in a different way. By placing a frog, rabbit, or pigeon under the influence of chinoline, the animal remains motionless. A small portion of the surface of the cranium is then removed so as to expose a portion of the brain. One of the electrodes is brought into contact with the surface of the cornea, and the other with the surface of the brain. The blood is still circulating. A current is obtained; and all the effects I have just mentioned may be observed with ease. The animal remains in this condition, retaining its sensibility to the action of light, for as long a period, in the case of the frog, as forty-eight hours. These observations led to the discovery made recently, that there is no necessity for even exposing the surface of the brain. That is to say, the action of light can be traced, if needful, through the whole body. If, for example, we take a frog, place it in position, slightly abrade the skin on the surface of the head or back, or any part of the body, then adjust the electrodes, one in front of the cornea and the other upon the abraded skin, we obtain an electrical current which is affected by light in the usual way. But if the electrode in contact with the cornea be shifted to some other part of the body, a current may be obtained; but this current is not sensitive to light. In order to produce the specific action of light upon the eye, the retina must be included in the circuit. This discovery enabled us to perform many experiments without injuring the animal, except to the extent of abrading or removing a small portion of skin. It at once opened up the way for making observations upon warm-blooded animals (one of the chief difficulties in our earlier investigations). For example: give a rabbit or a guinea-pig a small dose of chinoline, and the animal remains prostrate and quiet. Then cut off a little of the hair from the surface of the head at the back of the neck, and abrade the skin so as to have a moist surface; bring the electrodes into position, placing one in contact with the abraded surface, and the other in contact with the surface of the cornea, and you will at once obtain the effect.

Action of Light in Warm-blooded same as in Cold-blooded Animals.—By the use of chinoline we were able to make experiments of the kind just described for a considerable time, without the necessity of maintaining artificial respiration. The result of those investigations upon warm-blooded animals has been to show that in these, as in the cold-blooded, light produces first an *increase* in the electric current on impact; continued light usually causes the electrical current to diminish; and on the removal of light, there is a second rise, as described in the case of the frog. In our earlier investigations, we always observed in the case of warm-blooded animals (when the eye had either been quite removed from the body or was receiving an inadequate supply of blood), that the action of light caused a negative variation, that is, a *diminution* in the electrical current. By improved methods, however, which have the effect of placing the eye in conditions more normal, we find that light causes a *positive* variation, that is, an increase; thus agreeing with what had hitherto been observed in the eye of the frog. This is a point worthy of notice. Du Bois-Reymond showed, even in the case of sensory nerves, that physiological action caused a *negative* variation. But it appears that in the case of the retina the action of the normal stimulus is to cause a positive, not a negative variation.

Experiment with the Living Lobster.—The action of light can be readily shown in this animal. Fix it loosely in a cloth, and lay it on the table in a slightly oblique position. With a small trephine remove a circular portion of the carapace, about three millimètres in diameter, and expose the moist tegumentary surface. Bring one electrode into contact with this surface, while the other touches the cornea. The usual effects of light may then be noted; but in the case of the lobster, the variation caused by the impact is greater than what we have noticed in any other animal, often amounting to one-tenth of the total amount of current. Another interesting experiment, comparable with that of the two eyes just described, may be made on the lobster by placing an electrode in contact with each cornea. The result frequently is apparently no current, but in reality the currents neutralise each other. Light falling on the one eye causes the needle to move,

[1] Friday evening Lecture by Prof. James Dewar, M.A., at the Royal Institution, March 31, 1876. See NATURE, vol. viii. p. 204.

say to the left, while if it fall on the other eye, the needle swerves to the right. When the eye of the lobster, removed from the body, was divided longitudinally into segments, each segment was found sensitive to light. The

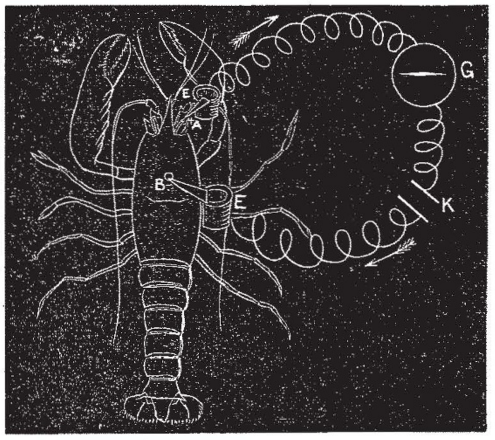


Diagram showing arrangement of apparatus in experiment on living lobster. A, corneal surface, having electrode. E, in contact with it. B, portion of carapace removed so as to expose moist surface for electrode, E. K, key. G. galvanometer. Arrows indicate direction of current.

effect of light was then to increase the primary current, but no inductive action was observed on withdrawal. This observation is interesting as a confirmation of the views of physiologists regarding the mode of action of a compound eye.

Mode of Experiment on Eye of Fish.—An experiment upon the eye of a fish may be made in a very simple way, by a method adopted in Prof. Stricker's laboratory in Vienna. Take a fish and give it a very small dose of woorara. It soon becomes almost motionless, and sinks in some cases to the bottom of the vessel. The animal would soon die in consequence of paralysis of the movement of the gills necessary for respiration. But, if we take the animal out of the water, put it upon a glass plate, introduce a little bit of cork under each gill, and then by means of an india-rubber tube placed in the mouth, allow a little water to flow over the gills, the fish will live out of water for many hours. By this method may be made the experiment upon the eye of a fish with like results.

Observation on Human Eye.—Having succeeded in detecting the action of light on the retina of the living warm-blooded animal without any operative procedures, it appeared possible to apply a similar method to the eye of man. For this purpose, a small trough of clay or paraffin was constructed round the margin of the orbit, so as to contain a quantity of dilute salt solution, when the body was placed horizontally and the head properly secured. Into this solution the terminal of a non-polarisable electrode was introduced, and in order to complete the circuit the other electrode was connected with a large gutta-percha trough containing salt solution, into which one of the hands was inserted. By a laborious process of education it is possible to diminish largely the electrical variation due to the involuntary movements of the eye-ball, and by fixing the eye on one point with concentrated attention, another observer, watching the galvanometer, and altering the intensity of the light, can detect an electrical variation similar to what is seen in other animals. This method, however, is too exhausting and uncertain to permit of quantitative observations being made.

Explanation of Variation in Direction of Current.—One phenomenon particularly attracted the attention of physiologists, and especially of those who first saw the experiments, viz., that sometimes, in the case of the eye of the frog, light produced an increase in the electrical current, and in other cases a diminution. This we could not at first account for. But we have been able to make out that the positive and negative variation, or the increase or diminution of the natural current on the action of light, depends upon the direction of the primary current, when the cornea and brain are in circuit. If the cornea be positive and the brain be negative, then light produces an *increase* of the electrical current. If, on the other hand, the cornea be negative and the brain positive, light then produces a *diminution* in the electrical current. It is thus conclusively shown that the current superadded, or if we may use the language, induced by the action of light, is always in the same direction; only in the one case it is added to, and in the other subtracted from, the primary current.

The Use of Equal and Opposite Currents.—Many experiments were performed in which equal and opposite currents were transmitted through the galvanometer at the same time. By the use of resistance coils, it was not difficult to balance the current from the eye; but, owing to the inconstancy of even a Daniell's cell in such experiments as these, it was impossible to avoid fluctuations which might possibly have been mistaken for those due to the action of light. This difficulty was got over by what was formerly called *the double eye experiment*, in which two similar eyes are placed in reversed positions on the electrodes, so that the current from the one neutralises that of the other. When this is accomplished, it is easy by means of a blackened box, having a shutter at each side, to allow light to fall on either the one eye or the other, and it is then shown that the galvanometer needle moves either to the right or left, according to the eye affected. Instead of removing the eyes from the head and balancing them as just described, it is a much better method to apply the two electrodes directly to the corneas in their natural position. By a little manipulation, it is possible to obtain two positions that seemingly give no electrical current. In these circumstances, light, allowed to fall on the one eye or the other, produces the effects above detailed.

Action of Polarised Light and Colours of Spectrum.—The next point investigated was the action of polarised light and the various complementary colours. Early experiments, by passing light through solutions having various absorptive powers and by the direct coloured rays of the spectrum, &c., lead always to the same conclusion—namely, that the most luminous rays produce the greatest effect. For studying the action of polarised light, the simple contrivance of a black box, having a hole on one side of it, placed over the eye, may be employed. Opposite the hole two cylindrical tubes of brass, each carrying a Nicol's prism, were placed, and between the two prisms a thin plate of quartz is introduced, producing the various colours of polarised light on rotating one of the prisms. The general results were exactly the same as with the colours of the spectrum. In all cases, the impact of the yellow rays produced the greatest effect. It has also been ascertained by this method that the effect of the *impact* of light is much more regular than the effect of its removal. The results of one series of observations are given in the two following tables:—

Action on Frog's Eye of Colours of Polarised Light.

	Initial Effect.	Final Effect.
Purple	rise of 3	rise of 14
Light blue	,, 5	,, 12
Red violet	,, 5	,, 15
Blue	,, 7	,, 20
Red	,, 8·5	,, 15
Orange red	,, 10	,, 22
Green blue	,, 10	,, 24
Green	,, 13	,, 24
Yellow	,, 16	,, 24
Rose	,, 8	,, 19

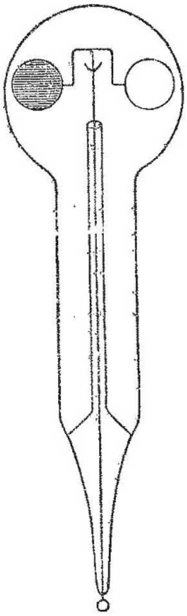
Action on Frog's Eye of Spectrum of Oxyhydrogen Flame.

	Initial Effect.	Final Effect.
Yellow, near orange ...	rise of 70	rise of 10
Green yellow	,, 25	,, 5
Green—low	,, 15	,, 0
Green—high	,, 15	,, 0
Green—higher	,, 18	,, 8
Yellow green	,, 85	,, 35
Yellow	,, 80	,, 40

(*To be continued.*)

SIR WILLIAM GROVE ON THE RADIOMETER[1]

SIR WILLIAM GROVE described some experiments he had recently made with a modification of Crookes's radiometer. After a few prefatory trials, such as coating one-half of the bulb with tinfoil and electrising it, which gave no notable results, he devised a method, shown in the accompanying sketch, by which he could electrise the whole of the internal system. Four aluminium vanes, each blackened on one side, had metallic arms and a metal point at their crossing that rested in a metal cup. The latter was united to a platinum wire that passed through a glass tube and was fused into it, the platinum wire protruding. Lastly, the glass tube was fused inside the apparatus and hermetically sealed, the end of the platinum wire being exposed. The vacuum in this apparatus was considered by Mr. Crookes[2] to be as perfect as in his radiometers generally, but Sir Willam Grove doubted that it was so. The following were the results:—



1. With the faint light of a lucifer match or of one or two candles, the vanes invariably turned the opposite way to the normal, the polished surface being repelled. With a dark heat, as from an iron shovel heated short of redness, they went the normal way. These effects continued for several days, but not permanently; the apparatus seemed to have leaked and to have become sluggish and irregular.

2. On electrising the protruding platinum wire with a rubbed rod of glass or sealing-wax, the vanes rotated sometimes one way and sometimes the other.

3. On connecting the negative pole of a Ruhmkorf's coil the results were uncertain, but the positive pole caused the vanes to rotate steadily, and its effect was even better than that from light or heat. In the dark the effect was very beautiful, as the dark vanes moved through a phosphorescent glow. The total results were considered by Sir William Grove to be somewhat negative, but they tended to show that all the effects were due to residual air. He suggested in explanation of the last experiment, that more electricity would escape from the rough than from the polished faces of the vanes, as the former presented a vast number of points. Consequently the rough faces would produce more disturbance of the gas in front of them, and would themselves be more affected by the reaction than the plane faces. The polished surfaces being repelled by luminous heat is, however, very difficult of explanation.

In his second notice Sir William Grove described some further experiments he had made with Crookes's radiometers since the last meeting of the club. He did not now entertain much doubt that these movements are due to the effect of residual air. Mr. Crookes had kindly made a second instrument for him, and the one that he described at the last meeting, of which the vanes were metallic and in metallic connection with a platinum wire that protruded outside the apparatus, had been re-exhausted. Both now act normally, the black faces of the vanes being repelled by light and by heat. When the protruding wire is now electrised by a Ruhmkorf's coil the effects that were previously observed are altogether absent, there is not the slightest luminosity round the vanes, and the current does not pass. But although the current is now incapable of traversing the small space of one-tenth of an inch that separates the vanes from the glass, induction acts across it just as well as before. This is shown by the readiness with which the vanes follow the movements of a piece of rubbed glass or sealing-wax held near the apparatus. It is therefore evident that the effects of attenuation of air upon discharge and upon induction are not the same. When attenuation has commenced and is increasing, the discharge passes more and more rapidly, until it becomes a glow, or according to the old theory of electricity, polarisation becomes more and more readily subverted; but a further attenuation stops the discharge entirely. On the other hand, induction continues, and appears to be in no way lessened by extreme attenuation. These results cannot be accounted for by the old theory that discharge is the consequence of subverted induction.

It farther appears that a radiometer is a most delicate electroscope. By tilting it until the vanes touch the glass, the interior of the glass may be electrised, and it will then remain for days in that condition. He had performed this operation eight days ago, and the movements of the instrument by light or heat have been thereby wholly checked. Every endeavour has been made to discharge or neutralise the electricity on the glass surface, as, for example, by covering the exterior of the globe with tinfoil and connecting this with the platinum wire, nevertheless the glass remains charged, showing what a perfect insulator a good vacuum is.[1]

The above is a copy of the abstracts in the club book. They are now further published, as some partial notices of them have appeared in foreign journals. W. R. G.

[1] Abstract of two communications by the Hon. Sir William Grove, F.R.S., to the Philosophical Club, May 18 and June 15, 1876.

[2] Who kindly made it for me from my description.—W. R. G.

[1] I may state that the electricity did ultimately become dissipated, but not until several weeks had elapsed.—W. R. G.

THE NORWEGIAN NORTH SEA EXPEDITION, 1876[2]

II.

Researches relating to the Salt-water Fisheries.

BY the side of the more strictly scientific researches it was also our intention during the expedition, if opportunity offered, to give close attention to all the circumstances that might stand in any connection with or throw any light upon our most important salt-water fisheries. As I already during a series of years had been engaged in the study of our fisheries, the prosecution of these researches was committed to me.

For this reason there was added to our other equipment various fishing apparatus, as hooks and lines for deep-sea fishing, and several sorts of drag-nets with various sizes of mesh. The use of such implements could, as a matter of course, only be reckoned upon in good weather and with a pretty smooth sea, which we, however, had promised ourselves might occur at least now and then during our three months' excursion at the best season of the year. But the state of the weather was unfortunately so utterly unfavourable during our whole expedition that the employment of the apparatus we have referred to was not to be thought of. For the same reason the apparatus for measuring the velocity of the currents, exceedingly important in the first place for the physico-meteorological researches, but also for those with which we are now concerned, could not be brought into use. During the few fine days we had in the course of our expedition we were too near the coast for these researches to have any special interest.

Although the state of the weather thus laid insurmountable obstacles in the way of the researches referred to, I have, however, during our expedition, been able to establish certain facts which, in my opinion, are of no inconsiderable importance in this direction, and will be of great use in guiding us in the continued practical scientific researches concerning our fisheries. It is of these facts that I now proceed to give some details.

It is ascertained by our soundings that off our coast there are several fish-banks of whose existence there was no previous knowledge, and on which a profitable fishery with bank vessels may certainly be carried on during the summer months.

The so-called "Storegg" (great edge) off Romsdal's Amt has been from old times famous for its immeasurable richness in fish, and there has been an obscure tradition that it was not the only point where such fishing could be carried on on a large scale, but that there were to be found similar rich fish banks at many other points far out in the open sea, "were man only fortunate enough to fall upon them." The mystic account of the "Havbro" (sea

[2] By Prof. G. D. Sars From Christiania *Dagbladet* of January 27. Continued from p 414.