POINTS RELATING TO THE WEBER-FECHNER LAW. RETINA; MUSCLE; NERVE.

Being the substance of a communication to the Neurological Society, March 7, 1895.

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THE Weber-Fechner law in its restricted sense designates the relation between magnitude of sensation and magnitude of stimulation. I am using it at present in a more extended sense to designate the relation between cause[1] and effect in living matter, and as instances that I have been able to study I shall bring under your notice experiments upon (1) the retina, (2) muscle, (3) nerve.

The ordinary view of the Weber-Fechner relation between sensation and stimulus presents the former as a logarithmic function of the latter.

Accepting this as in the main correct, and deferring discussion of the departures from the law that take place at the higher and at the lower limits, let us first face this definite question: there is a disproportion between stimulus and sensation such that equal increments of sensation require increasing increments of stimulation, or—what amounts to the same thing—that each equal increment of

[1] The word "cause" is here used in its popular sense, to denote the immediate discharging cause, not in its strict physical sense, when of necessity cause and effect are equal and opposite. Evidently it is only in the first sense of "discharging cause" that the stimulus of a nerve is the cause of muscular contraction, just as in the same sense a spark is called the cause of an explosion, or a match the cause of a fire. The unstable equilibrium of fuel, or of powder, or of nerve-matter is obviously a factor in the aggregate causation, particular elements of which are treated as terminals of thought when, *e.g.*, we consider the relation between magnitude of stimulus and magnitude of contraction, or between magnitude of stimulus and magnitude of sensation.

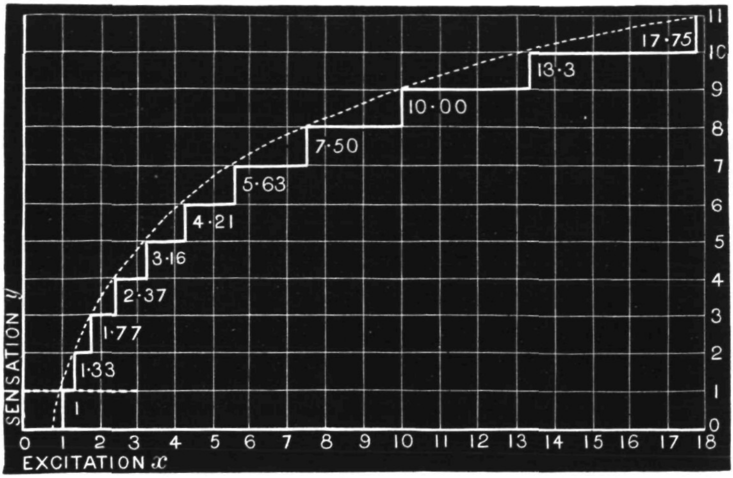

FIG. 1 A.

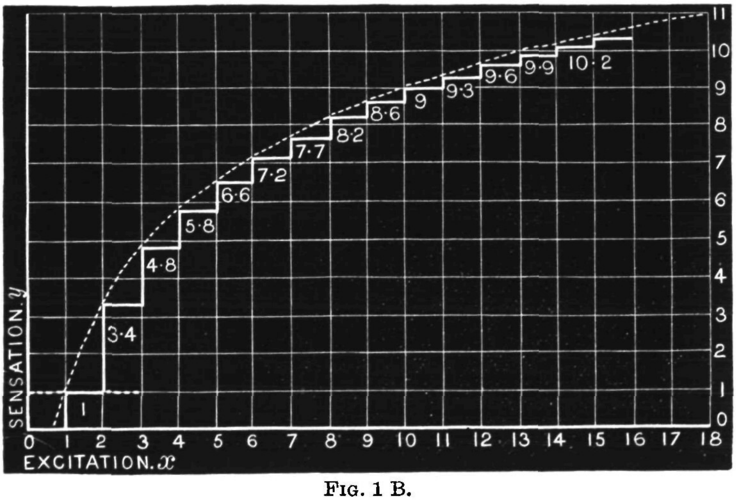

FIG. 1 B.

The Weber-Fechner curve, expressive of a logarithmic relation between excitation (increasing along the abscissa) and sensation (increasing along the ordinates). The two curves, A and B, are identical. In A the curve is obtained by taking along the abscissa the magnitudes of excitation required to produce "the minimum perceptible difference" between successive stimuli assumed by Fechner as the unit of sensation. In B the curve is obtained by calculating the magnitudes of sensation corresponding to an arithmetical increase of excitation. Both curves show, therefore, the same relation, A showing that to equal increments of sensation increasing increments of stimulation are necessary, B that equal increments of stimulation cause diminishing increments of sensation. In A the steps of sensation are equal, but each tread is longer than its predecessor; in B the steps of sensation diminish in the ascending scale, their treads being equal. The curves are constructed from numbers corresponding with an increase of excitation by $\frac{1}{3}$ necessary to produce a perceptible increase of sensation.

stimulation produces a diminishing increment of sensation. Is this disproportion of physiological or of psychological origin?

To present this question clearly it is convenient or even necessary to distinguish two stages in the passage from external physical stimulus to sensation; a not infrequently committed ambiguity in the use of the word "stimulus" will thereby be avoided.

We have:—

(*a*) the external stimulus, *i.e.*, the objective phenomenon or external cause of excitation apart from the excitation itself.

(*b*) the internal stimulus, *i.e.*, the material sensificatory change, provoked in the nervous system by the external stimulus.

(*c*) the sensation itself, *i.e.*, a subjective phenomenon concomitant with the sensificatory change.

Given, *e.g.*,

A series of external stimuli of magnitudes 1, 2, 3, 4, 5, &c., and a series of sensations of magnitudes 1, 3, 5, 6, 7, &c. Does the disproportion take place on physiological ground between external stimulus (*a*) and internal stimulus (*b*), or on psychological ground between internal stimulus (*b*) and sensation (*c*)?

Some contribution towards an answer to this question would be afforded if we could measure and express in any scale of units a series of internal sensificatory changes—effects of a series of external stimuli, their cause.

I.—On these grounds I have bestowed a considerable amount of attention upon the RETINA, where, thanks to the labours of Holmgren, followed by Dewar and MacKendrick, Kühne and Steiner, and others, we know that the stimulus of light produces an electrical change that may be utilised as the objective sign of a physico-chemical change in the retina. It is not proved, but it is highly probable, that such physico-chemical change is the sensificatory phenomenon in so far as the retinal portion of the retino-cerebral organ is concerned. For the purposes of the present inquiry this may be assumed, and we may proceed to measure out quantity of external stimulus (light), and read off upon the galvanometer quantity of physico-chemical change, considering such physico-chemical change as an instance of internal stimulus or sensificatory phenomenon.

Here is an example of retinal action consequent upon luminous stimuli of increasing magnitude.

The magnitude of stimulation was in this case varied by altering the distance from the retina of a standard candle; the object submitted to experiment was the freshly-excised eyeball of a frog, resting upon one electrode by its posterior surface, which included the cut stump of the optic nerve,

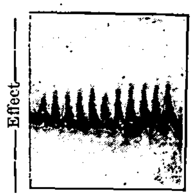

FIG. 2.

Fig. 2.—Galvanometric deflections (*i.e.*, retinal effects) in a frog's eyeball caused by exposures lasting one-eighth of a minute at minute intervals to the light of one candle at the distances 14·1, 10, 7·07, 5·77, 5, 4·47, 4·08, 3.78, 3·53, 3·33, 3·16 feet giving stimuli of the strengths: 0·5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 units, the unit taken being equal to $\frac{1}{100}$ of a standard candle at a distance of one foot. The curve obtained by joining the summits of the ordinates closely resembles the Weber-Fechner curve of fig. 1.

led off to the galvanometer by that electrode and by a second electrode, the actual end of which consisted in a saline-moistened thread resting upon the edge of the cornea. The eyeball was adjusted inside a dark box opposite to a blackened tube, through which light was let in or blocked off by the movements of a shutter not connected with the box, moved by hand or by an electro-magnet. The cornea was directed upwards—light impinged upon the sclerotic, glancing over and reflected from the surface of the eye-ball, so that there was no appreciable focussing of the candle flame through the refractive media of the eye. In the

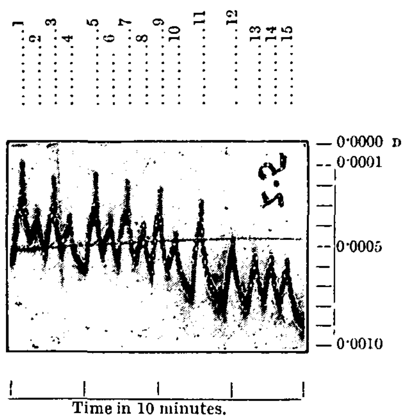

FIG. 3.

Fig. 3.—Galvanometric deflections by retinal currents produced by steady and by interrupted illumination of different intensities.

(1) Steady light at 10 units for 1 min.
(2) Interrupted ,, ,, ,, $\frac{10}{4}$ or 2·5 units.
(3) Steady
(4) Interrupted
(5) Steady
(6) Interrupted
(7) Steady
(8) Interrupted
(9) Steady
(10) Interrupted
(11) Steady at 40 units for 1 min.
(12) Interrupted ,, ,, $\frac{40}{4}$ or 10 units.
(13) Steady at 2·5 units for 1 min.
(14) ,, ,,
(15) ,, ,,

N.B.—The interruptions of light were caused by a revolving disc with open sectors giving 10 interruptions per sec. The sum of the sectors occupied $\frac{1}{4}$ of the whole disc.

The particular points illustrated in this figure are:

(1) That at equal strengths interrupted light produces a smaller effect than continuous light.

(2) That at unequal strengths the effect of interrupted light at 10 units is about equal to that of steady light at 2·5 units, and of steady light at 10 units to that of interrupted light at 40 units, the open sectors being $\frac{1}{4}$ of the disc.

	Interr. 10.		Steady 2·5.
Compare deflections	2, 4, 6, 8, 10,	with	13, 14, 15
	Steady 10.		Interr. 40.
,, ,,	1, 3, 5, 7, 9	with	12

particular experiment of which fig. 2 gives the results, the light was blocked off for seven-eighths of a minute and let on for one-eighth of a minute, during each successive minute, by means of an electro-magnet in the circuit of a battery and a mercury pool at which contact was made by a metal point fixed to a clock wheel and revolving once a minute. These instrumental details need not be minutely described; the apparatus may be inspected in the dark room; its plan is diagrammatically presented in fig. 13.

A simple inspection of fig. 2 shows us that the heights of the ordinates (*i.e.*, the magnitudes of effects) corresponding to an arithmetical increase of causative stimuli along the abscissa, do not form a straight line, but a curve, concave to the abscissa—a curve increasing by diminishing increments. It is similar in character to the classical Weber-Fechner curve given above.

I have also graduated the light by means of a revolving disc, with open sectors, the size of which could be varied. Fig. 3 exhibits the results of such an experiment.

This of itself is, I think, justification enough for an answer to the question formulated a few minutes ago—which I formulated in other terms two years ago—"Is the material sensificatory brain-change proportional to the internal stimulus, and the sensation some geometrical function of that change, or is the material change itself a geometrical function of the stimulus, and attended with sensation in direct proportion to its own magnitude?"[1] I then felt entitled to no opinion of my own, but quoted authorities *pro* and authorities *con* without adding note or comment. But looking to this result, considering that in fig. 2 we have external stimulus along the abscissa, internal stimulus along the ordinate, our judgment must be strongly inclined towards the second alternative.

II.—Let me at once turn your attention to a second item in the case, viz., to MUSCLE.

[1] Introduction to "Human Physiology," 2nd edition, p. 550.

Considering muscle, not for its own special sake, but in a most general light as excitable living matter, of which the chemico-physical response to external stimuli is measurable, we may study as an instance of the relation between causative stimulus and excited effect, the relation in muscle between magnitude of stimulation and magnitude of contraction.

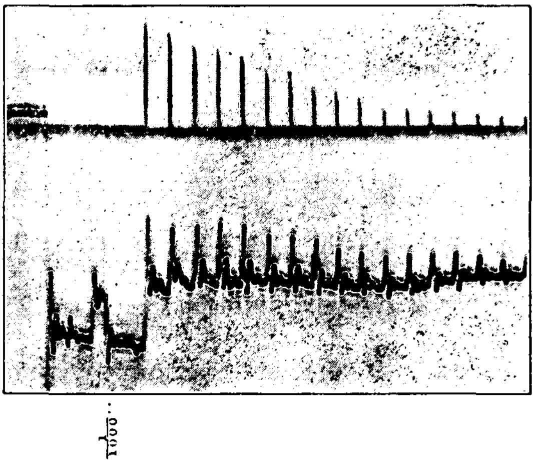

FIG. 4.

Simultaneous tracing of muscular contraction, and of the accompanying current of action. Galvanometer shunt $\frac{1}{50}$. Preliminary upward deflection by $\frac{1}{1000}$ volt.

We might do this galvanometrically, but the galvanometric sign of action in the case of muscle is simply a *replica*[1] of its mechanical response, and the latter is far more simply examined. I have urged elsewhere that as regards mechanical response, it is better to adopt an approximately isometric than an approximately isotonic method.[2]

[1] This is not, strictly speaking, correct; the electrical signs of muscular action are a far more delicate, and in some respects more accurate, quantitative indication than are the mechanical signs; moreover, the electrical response outlasts the *visible* mechanical response.

[2] "The Sense of Effort," BRAIN, 1891, p. 186.

An inspection of the two figures 5 and 6 shows that the general law, diminishing increments of effect (contraction), produced by equal increments of cause (stimulation), is similar to that already observed in the case of sensation, and in that of sensificatory change.

I do not now wish to dwell upon details, nor technical matters, nor historical matters, but before passing on to our next case I should like just to mention that the position here taken up has been considered and studied by other observers. Fick, Hermann, Preyer, Santesson, Cybulski and Zanietowski have handled the question, and Preyer in particular

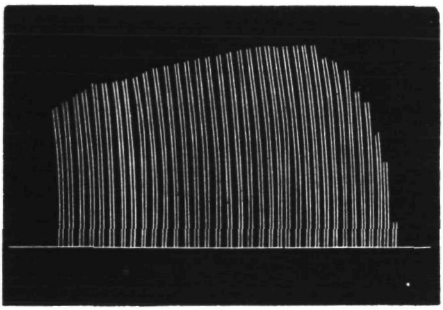

FIG. 5.
(To be read from right to left.)

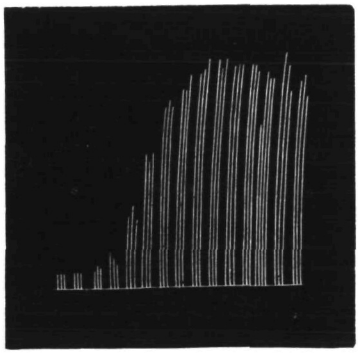

FIG. 6.
(To be read from left to right.)

Contractions of a frog's gastrocnemius in fig. 6, caused by induction shocks of arithmetically increasing strength in fig. 5, caused by the discharges of arithmetically increasing quantity from a condenser.

Fig. 5 exhibits a curve of increasing effect with diminishing increments, viz., at once concave to the abscissa.

Fig. 6 exhibits an S-shaped curve of increasing effects, viz., at first convex then concave towards the abscissa.

has considered it from the general point of view here taken up as indicated by the title of his monograph, "Das myophysisches Gesetz," Jena, 1894, the chief conclusion of which is to the effect that the shortening of muscle varies as the logarithm of the electrical excitation.[1] The other point

[1] And Dubois, in his admirable monograph on *Pholas Dactylus*, urges the same idea on still more cogent data, involving as they do both motion and sensation. In his account the magnitude of the "mouvement avertisseur" giving rise to the dermic phosphene, is a logarithmic function of the magnitude of stimulation, and the magnitude of the reflex retraction of the syphon symptomatic of sensation is proportional to the magnitude of the "mouvement avertisseur," which is the antecedent link in the sensificatory process.—"La Pholade Dactyle," Paris, 1892.

to which I wish to call your attention in passing is one that from a totally different standpoint has been insisted on by Prof. Weldon, and is illustrated in fig. 6.

The ordinates do not give from the outset a diminishing increment leading to a curve concave to the abscissa, but at the very outset increasing increments, and later only the usual diminishing increments. The curve formed by joining the summits of the series of contraction ordinates is S-shaped, beginning convex to the abscissa, continuing concave to the abscissa. And, as we shall see in a moment, a similar mode of commencement is apparent in the case of nerve (*e.g.*, in fig. 7).

III.—The third case to be considered is that of NERVE. Here (if I am not grossly deceiving myself, and have not fallen into some unsuspected form of instrumental fallacy) the results are of the highest interest. On nerve the curve expressing the relation between cause and effect is a straight line, the effect is proportional to the cause, at least within moderate ranges of excitation, exceeding, however, the upper limit of maximum functional effect, as gauged by muscular contraction. I hasten to add a short description of the conditions of experiment. The usual nerve-muscle preparation is laid across two pairs of electrodes; the exciting electrodes from an induction-coil are against the nerve midway between the leading-off electrodes to the galvanometer and the muscle, which in this case is preserved as an accessory indicator of function in the nerve. The electrical effects on the galvanometer and the mechanical effects on the muscle are simultaneously recorded on the photographic plate in a way that would be tedious to describe. It will be obvious if you will glance at the apparatus; its plan is diagrammatically presented in fig. 14. All precautions known to me for the avoidance of the two chief fallacies in such an experiment, viz., electrotonic currents and unipolar action, have been observed.

Fig. 7 exhibits the point I have just stated; the electrical effects on nerve consequent upon stimuli of magnitudes 1, 2, 3, 4, are in the proportion, 1, 2, 3, 4, a point that is still

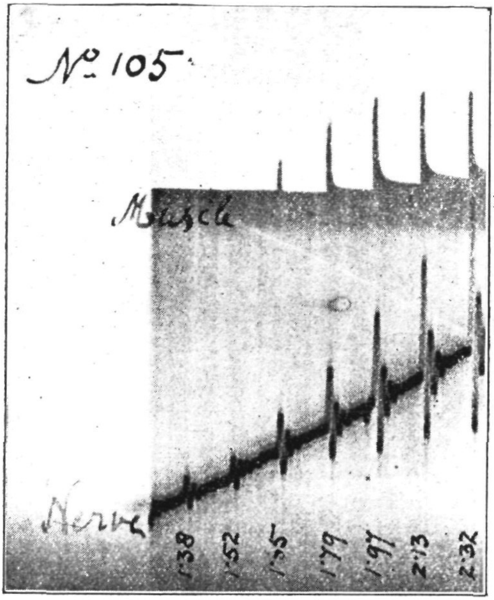

FIG. 7.

	Strength of Stim.	Nerve Neg. Var.	Muscle Lift.
No. 1	1·52 units ..	2·5 mm. ..	0
,, 2	1·65 ,, ..	5 ,, ..	4
,, 3	1·79 ,, ..	7·5 ,, ..	9
,, 4	1·97 ,, ..	12 ,, ..	12
,, 5	2·13 ,, ..	15 ,, ..	12·5
,, 6	2·32 ,, ..	19 ,, ..	12·5

Simultaneous tracing of the galvanometric and muscular effects of nerve excitation. The nerve of a nerve-muscle preparation led off to the galvanometer by unpolar electrodes to its central end, is excited by tetanising currents at intervals of 1 min. for periods of $\frac{1}{8}$ min. No galvanometer shunt; each centimetre of swing = about $\frac{1}{10000}$ volt.

N.B.—The current of injury of the nerve was such as to deflect the spot downwards as regards this tracing; the upward inclination of the galvanogram indicates the usual decline of that current; the upward black lines across the galvanogram are due to the negative variations, the subsequent downward black lines are due to after-oscillations of the magnet and mirror. The plan of experiment is shown by fig. 14, but as printed the tracing is reversed, *i.e.*, the muscle shadow was south of the nerve deflection, and the current of injury was north (cut end of nerve to north terminal) and the negative variation south.

more evident in the diagram fig. 8, constructed from corrected data in continuation of the experiment, part of which is given in fig. 7.

The chief positive results have been laid before you, and will have to be matured by further experimental criticism. The main question of the Weber-Fechner relation between stimulation and sensation is touched by them at more than one of its facets. The more general question of the

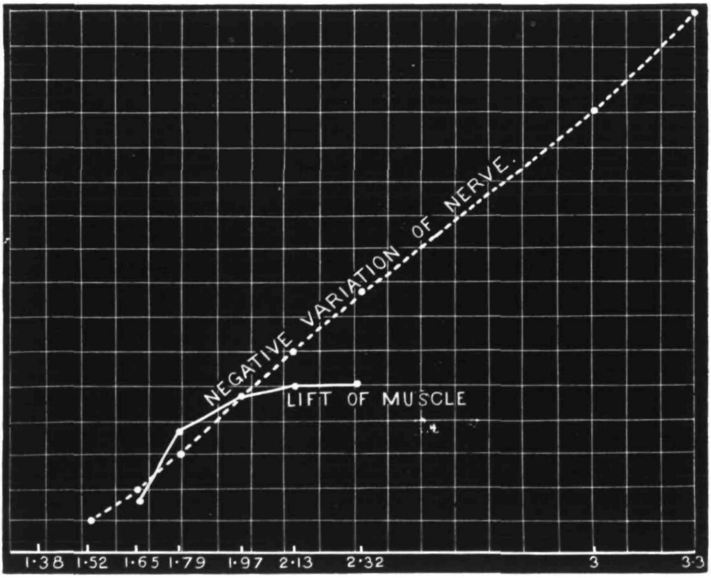

Fig. 8.

Stimulation units along the abscissa; electrical effects in nerve, and simultaneously observed mechanical effects of its muscle, along the ordinates.

relation between physical cause and physiological effect has *ipso facto* been involved. And as in any consideration of phenomena *de tactu*, side-views of phenomena accessory to the main inquiry have presented themselves, and glimpses of imperfectly viewed relations—what may be termed subpositive considerations—have also offered themselves to mind. In this connection the following points seem to me to be the more considerable :—

(1) The S-shaped curve of muscle exhibited, *e.g.*, in fig. 6—is it peculiar to muscle, or to muscle as representative of living matter? Will it find itself repeated in a Weber-Fechner sensation curve? I am unable to say. I have no *data* of my own with regard to that most difficult investigation, viz., that of the sensation curve low down, as it is rising from the threshold of stimulation. But I would ask you to consider probabilities. Which should we prefer—to have maximum increments of sensation to equal increments of stimulation low down in the scale close to the threshold, or higher up in the scale within the working range of the stimulation experienced in ordinary life? The first alternative would, it seems to me, be characteristic of an almost intolerable state of hyperæsthesia in relation to the tumult of minute stimuli by which we are surrounded. I should prefer to be endowed with an S-shaped curve. And this is not merely a personal preference; there are one or two significant hints from various sides pointing towards the conclusion that an S-shaped curve is typical of the response of living matter, whether by quantity of sensation, or by quantity of motion, or by quantity of loss of motion, in response to external stimulation, to physiological accidents and to pathological injury.

It is only in the medium range of the scale of sensation that the logarithmic curve comes out. Hering and his pupils, working at lower ranges, found that the curve was approximately a straight line. Considering the enormous difficulties attendant upon such experiments, it is easy to believe that the initial tail of an S should present itself to the observer as a straight line. In the case of a muscle—if it is allowable to regard muscle as a representative of living matter, and the physico-chemical changes taking place in it in consequence of stimulation as analogous with the sensificatory physico-chemical changes taking place in the living matter of sensory organs—we have this S-shaped curve outward and visible. And on this same living matter —muscle—the decline at death and the decline in fatigue, as far as I have been able to judge, run this S-shaped course, only the S of the waning is as the S of the waxing reversed—as if viewed in a mirror.[1]

(2) The second most thought-arousing point is with regard to the electrical signs of nerve activity—of the nerve-fibre, not of the nerve-cell. I pointed out some ten years ago, quite independently of the observations of Wedenski and Bowditch, that nerve-fibre is practically inexhaustible, a force-transmitting, not a force-transforming organ, a passive physical conductor. I then made certain reservations as regards the experimental fallacy of electrotonic currents, which have been removed by further investigation, and the conclusion is at present an admitted one. Well, the conclusion being admitted, I do not think that it need surprise us to find in such an organ the physico-chemical effect simply proportional to the physico-chemical cause.

I hasten to add that it is only within a certain range—a range far exceeding, however, the physiological working-range of nerve—that the simple proportion holds good. Many more experiments directed to this particular point will be required before I shall be able to lay an entire curve before you with any justifiable degree of confidence. All I am entitled to say at present is that within what may be termed physiological limits, the curve expressing the ratio between cause and effect is a straight line; the sub-minimal and supra-maximal ends of that curve require further experimental determination; as far as my experiments have yet gone it has appeared to me that the beginning of the curve is convex to the abscissa, the end of the curve concave to the abscissa.

[1] Without unduly insisting upon its possible significance, the fact is perhaps worth noting that an ordinary simple contraction of muscle due to a single stimulus, consists in each of its two parts of an S-shaped curve; in the period of ascending energy, the rise is by increments increasing, then diminishing, in the period of descending energy the fall is by decrements at first increasing then diminishing, giving ∫∿. The rising and falling effects have respectively their immediate cause in the muscle; it may be that each such cause is of uniform speed, in which case the effect is slow—quick—slow with uniform cause; or it may be that each such cause is itself slow—quick—slow, with its effect correspondingly slow—quick—slow; but even in this case there is an S-shaped relation between cause and effect, inasmuch as the immediate cause is itself an effect of a previous cause, the instantaneous stimulus provocative of decomposition of matter and evolution of energy, during the rise followed by what may be regarded as a negative state, provocative of recomposition and involution of energy during the fall.

Considering only that part of the nerve curve corresponding with the functional range between minimal and maximal muscular effects, we have a straight line, below which a short initial tail is convex to the abscissa, and above which, after a further prolongation of the straight line, the curve tends to become concave to the abscissa. An entire curve may then be considered as composed of three portions: (1) a short subminimal portion, convex to the abscissa, increasing by increasing increments; (2) a long straight middle portion, inclusive of the functional range between minimal and maximal muscular effect, increasing by equal increments; (3) an ultra-maximal portion far above the values of maximal functional effects, concave to the abscissa, increasing by diminishing increments.

It is not possible to exhibit these several features in any one line drawn to scale. To bring out the first portion of the curve the scale must be chosen very large, when of course the second and third portions are lost to view; to bring out the third portion the scale must be chosen very small, when of course the first portion is altogether indistinguishable. On an intermediate scale, the functional portion of the second portion is best shown, *e.g.*, in fig. 8. The first portion is visible in fig. 7. The third portion can be constructed from the numbers of fig. 9.

(3) A third point is subsidiary to the above. It will be most clearly exposed to you by the examination of an actual experiment (*e.g.*, fig. 9), viz., that far beyond that point where stimulation of the nerve gives a maximal effect upon the muscle, the effect upon the galvanometer of the electrical change in the nerve continues to increase. Due care was observed to exclude the unipolar and the electrotonic fallacies; the electrical effects were unchanged in direction with reversed direction of the excitation, viz., they were true "negative variations," the electrical concomitants of excitatory changes in the nerve. This being so, we are bound to recognise that the magnitude of an excitatory effect in nerve-conductors provoked by electrical excitation, is no index to the magnitude of functional disturbance within what may be regarded as physiological limits.

Method.—The most essential feature of the method employed in the above observations was the use of photo-galvanographic records, by means of an apparatus (galvano-

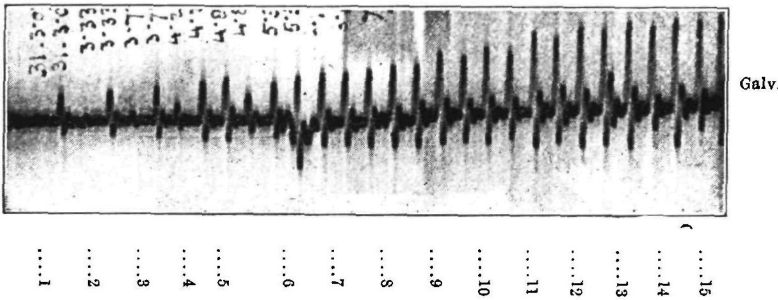

FIG. 9.

Continuation of Obs., 105. Galvanometer shunted $\frac{1}{10}$.

	Stimulation strength.	Galvanometric deflection.
No. 1	3·02 units	35 mm.
,, 2	3·33 ,, ...	40 ,,
,, 3	3·72 ,,	
,, 4	4·25 ,, ...	50 ,,
,, 5	4·80 ,,	
,, 6	5·50 ,, ...	60 ,,
,, 7	6·10 ,,	
,, 8	7·00 ,, ...	70 ,,
,, 9	8·20 ,,	
,, 10	9·60 ,, ...	85 ,,
,, 11	19·20 ,,	
,, 12	28·75 ,, ...	105 ,,
,, 13	38·30 ,, ...	110 ,,
,, 14	47·90 ,, ...	110 ,,
,, 15	57·50 ,, ...	110 ,,

N.B.—The values given for these galvanometric deflections are of necessity inexact, inasmuch as measurements of ordinates, the magnitudes of which have been tenthed by the shunt, and their subsequent multiplication by ten must give rise to a considerable error. But this error does not disguise the main fact apparent on simple inspection of the fig., viz., that the negative variation of nerve continues to increase with increasing strength of stimulation long beyond that strength which has produced a maximal muscular effect as shown by the preceding figure. The deflections to which numbers are not attached were caused by stimulation with reversed direction of current at the respective strengths indicated by the numbers, to exclude the suspicion of electrotonic currents.

graph) already described some years ago in another place,[1] modified in the present instance by the substitution of a sensitive plate for the sensitive paper previously used. The

[1] *British Medical Journal*, July, 1885, p. 135.

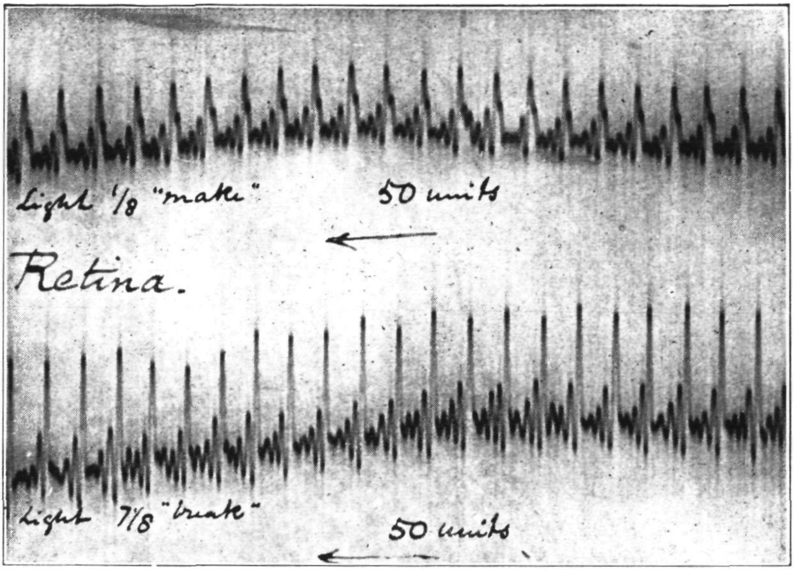

FIG. 10.

Currents of action from frog's retina six hours after excision of eyeball. The upper line is a series obtained by illumination for $\frac{1}{8}$ minute repeated each minute. Owing to the oscillation period of the magnet and mirror the deflection at "make" (about 4 mm.) is interrupted and augmented by the subsequent deflection at "break," the point of "break" is signified by the black spot of the large rise; the oscillations after the large rise are due to the swings of the magnet as it comes to rest. No galvanometer shunt. Each centimetre swing = about $\frac{1}{10000}$ volt. The lower line is a series obtained by illumination for $\frac{7}{8}$ minute repeated each minute. Only the "break" effects are visible, the "make" effects are not separately distinguishable. Oscillations of the magnet as before.

These series illustrate the facts that (1) the effects at "break" of light are greater than those at "make" of light; (2) the effects at "make" and at "break" do not sensibly diminish with repetition.

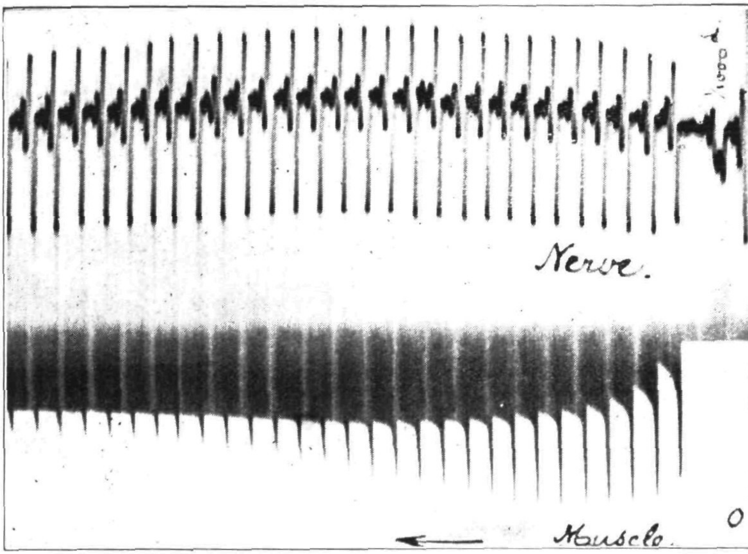

FIG. 11.

Simultaneous record of currents of action in nerve (upper line), and contraction of muscle (lower line), in accordance with the plan of experiment outlined in fig. 14. Tetanisation for $\frac{1}{8}$ min. repeated every minute. Galvanometer shunt $\frac{1}{9}$; preliminary downward or south deflection by $\frac{1}{1000}$ volt. Cut end of nerve to north terminal of galvanometer. Strength of coil 10 units. The electrical effects of nerve action do not sensibly diminish while the mechanical effects of the supplied muscle suffer the usual fatigue decline.

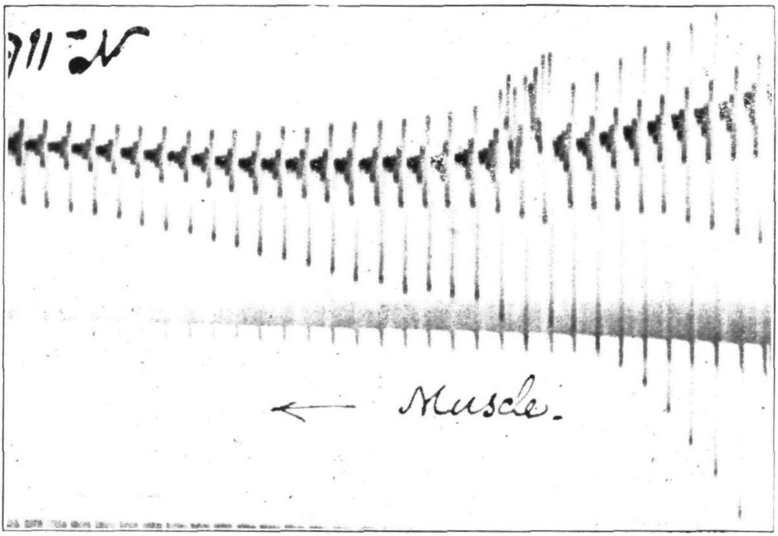

FIG. 12.

Simultaneous record of currents of action in muscle (large swings downwards, viz., south, the tendon being connected with the north terminal of the galvanometer, followed by the usual oscillations of the magnet as it comes to rest) and of the contractions of the same muscle. Galvanometer shunt $\frac{1}{9}$. Each centimeter swing = about $\frac{1}{1000}$ volt. Strength of coil 20 units. Tetanisation for $\frac{1}{8}$ min. repeated each minute.

N.B.—The muscular contractions (downward black teeth from the black border) are at first overrun and rendered indistinct by the large deflections of the magnet. The irregularity in the series was accidentally caused by the fouling of a wire.

The electrical effects of muscular contraction decline with the decline of the mechanical effects. The former are a more delicate index of the state of muscle than the latter.

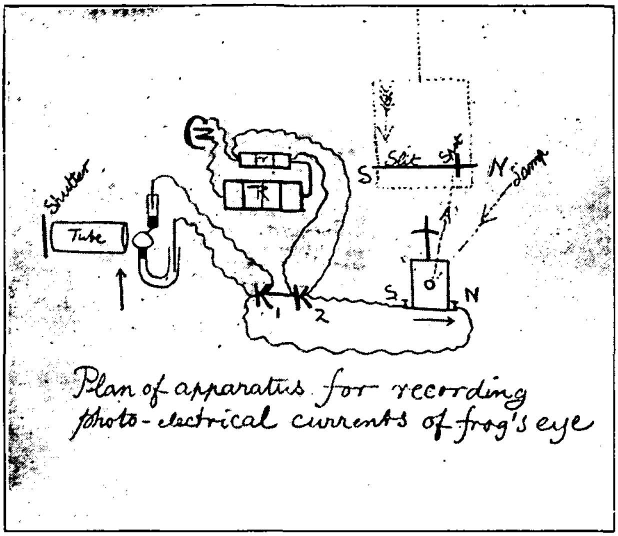
Shutter
Tube
S
Slit
Spot
N
Lamp
K1
K2
S
N
Plan of apparatus for recording
photo-electrical currents of frog's eye

FIG. 13.

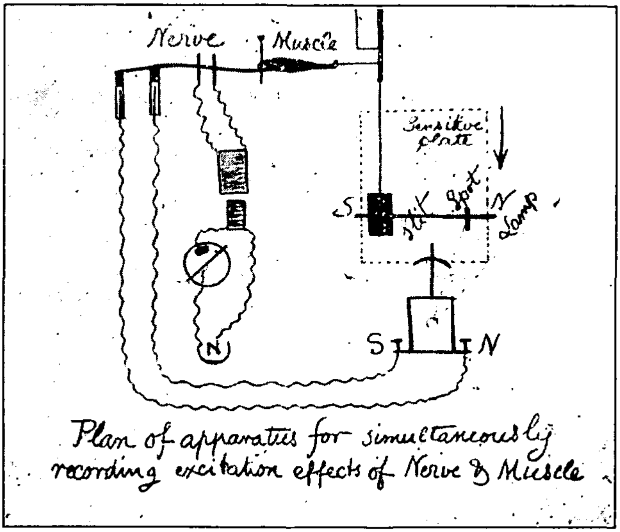
Nerve
Muscle
Sensitive
plate
S
Slit
Spot
N
Lamp
N
S
N
Plan of apparatus for simultaneously
recording excitation effects of Nerve & Muscle

FIG 14.

entire complexion of enquiries of the kind is altered when the photographic method is adopted; points that escape the closest scrutiny in its absence, come into striking evidence, and doubtful readings are replaced by peremptory writings—autographs of the objects under observation.

Seeing that the intensity of light falling upon the eyeball varies inversely as the square of its distance, I prepared a scale graduated in units, in accordance with the following scale of numbers, choosing for the unit the $\frac{1}{100}$ part of a standard candle at a distance of 1 foot, or 1 candle at a distance of 10 feet.

DISTANCE.	STRENGTH.
1 foot	100 units.
1·15 ,,	75 ,,
1·41 ,,	50 ,,
2 ,,	25 ,,
2·29 ,,	20 ,,
2·58 ,,	15 ,,
3·16 ,,	10 ,,
3·33 ,,	9 ,,
3·53 ,,	8 ,,
3·78 ,,	7 ,,
4·08 ,,	6 ,,
4·47 ,,	5 ,,
5 ,,	4 ,,
5·77 ,,	3 ,,
7·07 ,,	2 ,,
10 ,,	1 ,,
11·5 ,,	0·75 ,,
14·1 ,,	0·50 ,,
20 ,,	0·25 ,,

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