XXII. *On the Influence of the Galvanic Current on the Excitability of the Motor Nerves of Man.**

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[PLATES 64, 65.]

INTRODUCTION.

THE verification for undissected nerve of the established laws of electrotonus for dissected nerve has been the object of several previous researches. Of some the results have been negative, of others contradictory, of but few fairly confirmatory. PFLÜGER'S chief conclusions have received an occasional illustration from experiments made on Man, but these can hardly be said to carry support, still less independent proof.

The first definite experiments on the subject were made by FICK (Medic. Physik., 1866, p. 377). He tested his own ulnar nerve but failed to obtain any evidence of electrotonic change of excitability. EULENBURG (Arch. f. Klin. Med., 1867, p. 117) and ERB (ibid., pp. 238, 513) simultaneously came to opposite conclusions. According to EULENBURG, evidence of descending anelectrotonus and katelectrotonus was uniformly obtained by testing the nerve below the ascending and descending galvanic currents respectively. ERB, on the contrary, found the excitability diminished below the kathode, increased below the anode—an apparently anomalous result which HELMHOLTZ (Nat. Med. Verein., Heidelberg, 1867) attributed to rapid current-diffusion, and consequent establishment in the vicinity of the electrode, of opposite "odic" points in the nerve, wherever the current enters or leaves it. And, in effect, acting on this suggestion by testing the nerve with a small electrode, introduced through a large perforated electrode (polarising), ERB found the excitability diminished during anodic, increased during kathodic influence. SAMT ('Der Electrotonus am Menschen,' Berlin, 1868), who also sought for descending electrotonus, came to similar conclusions as EULENBURG, though his experiments were far from yielding uniform results; he attributes the inconstancy of the results to the "inconstancy of the

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nervous matter," a view in which he was followed by CYON ('Principes d'Electrothérapie,' Paris, 1872, p. 123), whose results were equally inconstant. BRÜCKNER (Deutsches Klinik, 1868, No. 43) and RUNGE (Arch. f. Klin. Med., 1870, p. 536) had recourse to the method of uniting the testing induction with the polarising galvanic currents in one circuit. They both obtained, in the main, similar results,—when the two currents flowed together, there was an increased effect both at the anode and at the kathode; when the two currents were opposed, the effect was diminished at both poles of the galvanic current, especially at the anode. In their interpretation, however, these two observers took opposite views. RUNGE explained everything by an assumed "summation" of electromotive forces; BRÜCKNER attributed the effects to physiological causes, though his arguments were not such as to carry conviction. None of these experimenters, with the exception of CYON, used the graphic method; they estimated the changes by watching the contractions.

METHODS AND RATIONALE.

We employed three modes of excitation: (1.) Induction currents; (2.) Makes and breaks of a continuous current; (3.) Mechanical stimulation. The electrodes* were applied as follows:—One electrode of large area—the "indifferent" electrode—was applied to any convenient part of the body remote from the part explored; the other electrode of small area—the "exploring" or "testing" electrode—was applied to selected points along the course of favourably situated nerves, and the effects at this movable electrode were alone considered.

We shall describe these effects under the polar terms "*anodic*" and "*kathodic*," without reference to any assumed direction of current in the nerve; for not only is the localisation of an efficient current in a given direction problematical for the imbedded nerve, but a simple experiment suffices to show that the position of the indifferent, whether central or peripheral to the exploring electrode, does not in any way influence the results obtained at either pole.

The condition which we thought necessary to fulfil throughout our experiments was the coextension of the points of excitation and of polarisation; our reason being that owing to current diffusion and consequent establishment of opposite electrodes in the nerve in the immediate neighbourhood of the electrode, the electrotonic state is variable in kind, degree, and distribution. This condition is fulfilled by conjoining the testing and polarising currents in one circuit, and by applying one electrode only to the nerve.† The other method, by which the two circuits are separate, gave in our hands discordant results, similar to those of previous observers, who found that the

* We did not use unpolarisable electrodes in these experiments, but plates of metal covered with chamois leather.

† This method was first used by ECKHARDT (Beiträge zur Anat. und Phys., Giessen, 1858-4, p. 28), afterwards by PFLÜGER ('Elektrotonus,' p. 394) and by von BEZOLD ('Erregung der Nerven und Muskeln,' p. 212); on Man it has been employed by BRÜCKNER (*loc. cit.*) and by RUNGE (*loc. cit.*).

effects varied in kind and degree.* HELMHOLTZ' hypothesis undoubtedly accounts for some of these apparent contradictions, which may be due to the fact that when a proximal region, or series of points, in a nerve is submitted to the polar action of a given electrode, there exists a distal region, or series of points, in that nerve which is submitted to polar influence of the opposite sign to that of the electrode (using the terms "distal" and "proximal" with reference to the electrode as centre).

But if this hypothesis is true in the case of the polarising current, it must hold also for the testing current, whether galvanic or induced, since the laws of diffusion are the same for both, and one cannot ensure the coincidence of excitation and polarisation by separate electrodes. Another contingency capable of vitiating the results obtained by this same method is, that derived currents may be established through the testing electrode of sufficient strength to alter the irritability of the nerve. We adopted the theory of a mixed polar action for both polarising and testing currents, as a working hypothesis at the beginning of our experiments, relying upon the following considerations to justify its assumption:—

(1.) The presence of an anodic make contraction speaks in its favour, since, given the axiom of PFLÜGER and CHAUVEAU, that make contraction is kathodic, break contraction anodic, it follows that with anodic make there coexists an associated kathodic make.

(2.) The elementary fact that, over certain points of nerve, the muscles that contract at anodic make are not the same as those that contract at anodic break also speaks in its favour, since it indicates that at the two events the points of excitation are not identical.

To denote the nerve-regions that are subjected to the two kinds of influence, we use the terms "*polar*" and "*peripolar*." The area of electrical influence within which the density is sufficient to produce physiological effect is schematically represented as consisting of a polar region immediately beneath the electrode, in which the electrical relation is of the same sign as that of the electrode, and of a surrounding peripolar region in which the electrical relation is of the opposite sign (Diagram I.). We shall use this representation for the most convenient expression of our facts; it must

* Our experiments with this method were few, and for the reasons given in the text we do not lay any stress upon the results obtained. These were as follows:—

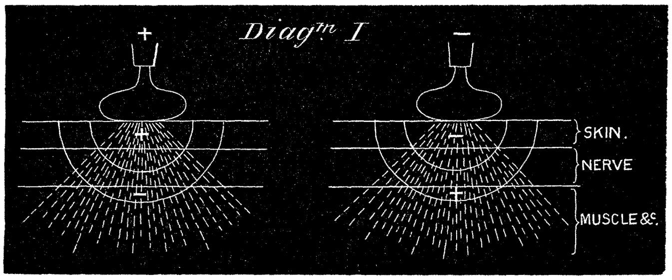
With the galvanic kathode above or below the negative polarising electrode the make contraction (K.C.C.) was diminished. On breaking the current a contraction appeared (K.O.C.?).

With the galvanic anode above or below the negative polarising electrode the break contraction (A.O.C.) was diminished; the make contraction (A.C.C.) variable.

On testing with the make and break induction currents the effect of the kathode of either was diminished in the neighbourhood of the polarising kathode, increased in that of the polarising anode; the effect of the anode was increased in the neighbourhood of the polarising kathode; variable in that of the polarising anode.

With reference to the after-effects, they appeared to show increase after diminution of effect; diminution after increase.

however be understood that we are dealing with physiological signs alone, and that we have not determined the actual physical conditions that underlie them. With the method we employ, the actual limits of the provinces of the two effects (anodic



and kathodic) are a secondary matter, for, admitting the existence of these effects, it is sufficient to know that they are coextensive for the two electrical components (testing and polarising) at the common electrode, that the principle of opposite polar and peripolar electrotonic states applies to the testing as well as to the polarising current, and that as the current density is greater in the polar than in the peripolar province, the electrotonic states are proportionately more marked in the former than in the latter.

To secure the coincidence of excitation with polar modification in the case of mechanical stimuli, we transmitted the testing blow through the movable electrode to a superficial nerve resting on bone.

The strength of the induction current was altered by altering the distance of the secondary from the primary coil of a DU BOIS apparatus. With the ordinary arrangement (one or two volts for the primary circuit and a resistance of about 1 ohm) the make induction shock is hardly effective on the human body, and examination is restricted to the effects of the break induction current. In order, therefore, to examine also the effects of the make induction current, we adopted the modification of HENRY,* viz., introduction of resistance into a primary circuit supplied by a battery of many cells, in order to obtain make and break induction shocks of about equal strength. The interruptions were made by hand.†

* See DU BOIS-REYMOND, 'Ges. Abhandlungen,' vol. i., p. 230; HENRY, Trans. Phil. Soc., Philadelphia, vol. viii., pp. 7, 8 (1840); and Phil. Magazine, vol. xviii., p. 488 (1841).

† This method gives sufficiently regular stimuli, as may be perceived from the figures, care being of course taken to make and break contact as uniformly as possible. To this purpose we employed a simple spring key in the battery circuit, removing the finger rapidly, so that the break was effected by the recovery of the spring. We may remark that whereas by breaking rapidly a more energetic current is obtained than by breaking slowly, the contrary obtains in the case of the make, where a more gradual contact is more effectual than a sudden one. We have, however, also used a capillary contact with a mechanical interruption as a relay without improving upon the regularity of interruption. We prefer the manual method because it requires less apparatus, and because the capillary contact is well suited for make only. Used for adding to or subtracting from a galvanic current, the latter method would also necessitate an undesirable period of short-circuiting, and we used a HELMHOLTZ' key as will be described.

The strength of the polarising current was varied by altering the number of cells (freshly charged LECLANCHÉ'S with conglomerate plates), and to avoid fallacies arising from changes of resistance occurring during experiment, controlled by a galvanometer constructed to measure from 1 to 50 thousandths of a B.A. unit (milliwebers). In order further to eliminate the error caused by changes of resistance (vide *infra*) we introduced an additional resistance into circuit, maintaining the current at its original strength by employing greater electromotive force (*e.g.*, by 4000 ohms + galvanometer resistance about 750 ohms, *i.e.*, three times that of the average resistance of the body in the conditions of our experiments, the possible effects of changing resistance are divided by four). By this device we ascertained that our results were practically independent of alteration of current strength by alteration of resistance. It occasioned, however, the observation that addition of resistance in the secondary circuit diminishes the effect of the anode of the induction current (make or break) far more markedly than that of the kathode, a point which is illustrated in Tracing 32.

We observed a fact of the same kind with the HENRY modification of the current, viz.: that on gradually increasing the strength of current by bringing the secondary nearer to the primary coil, a break positive effect, which appeared with lower strength, was gradually overtaken by the corresponding make negative effect, which under certain circumstances might even surpass the break positive effect with higher strength (Tracing 33). We found the former phenomenon to be independent of the nature of the resistance apparatus used, and of its position in the circuit. We did not find anything analogous for the anode and kathode of the continuous current, the diminution of the contraction at the anode being parallel to that at the kathode when the resistance in circuit is augmented; on the other hand, we noticed that when wire coils are used, with the same current strength, the make effect at both poles is greater without than with additional resistance in circuit, the break effect remaining unaffected. This diminution of the make effect is doubtless due to the generation of an extra current in the resistance coil.

To record the muscular contractions which give the measure of nerve-excitability, we employed a small thick indiarubber bag, strapped to the part chosen for exploration, and connected by a flexible tube with a MAREY'S tympanum. The excursions of the lever were recorded on a smoked cylinder travelling at a convenient speed (about 2 centims. per minute). We preferred this mode of estimating excitability by strength of contraction, to that of estimating it by minimum stimulus, and we only determined the minimum stimulus for the sake of comparison. Whether during polarisation, increase seen on the figure was due to increased contraction of a given amount of muscle, or to the added contraction of previously unexcited muscle, or to both factors, does not affect the evidence for our present purpose. We did not, strictly speaking, measure the nerve excitability, but only determined whether it was increased or diminished, for the amplitude of the record does not increase proportionally with the strength of contraction.

The greater number of our experiments were made on the peroneal nerve close to the tendon of the biceps, or at the head of the fibula, and all the accompanying figures were taken from the anterior tibial group of muscles. We, however, obtained similar results on other nerves, and with other groups of muscles, viz.: by stimulation of the supra-clavicular nerves, and of the median and ulnar nerves, using the muscles of the fore-arm as the indicator of effects. The experiments were made on ourselves.

I. Polar Alterations of Excitability tested by Induction Currents.

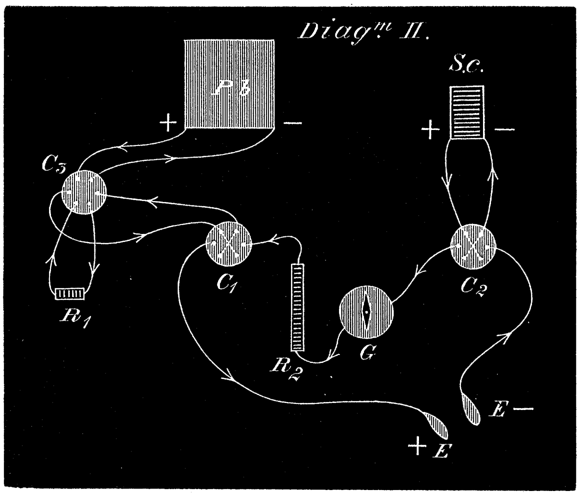
Preliminary.—Before using induction currents to judge of alterations effected by the galvanic current, we examined the effects of long series of induction breaks and makes. Our experiments gave the following results :—

1. The height of successive contractions by make or break induction currents approaches more and more gradually to a maximum. The figures show a marked and progressive increase, similar to the "stair-case" increase obtained with repeated excitations of the ventricle apex (Tracing 12).

2. The stronger the excitations the more rapid is the initial increase.

We do not propose to discuss these points here, but only record them in evidence of an alteration effected by induction currents, which must not be attributed to the galvanic current when it coexists. Anticipating upon some remarks we shall have to make on ascending and descending series by makes and breaks of the galvanic current, we interpret the progressive ascent to signify progressively increasing excitability as an after-effect of each successive excitation. We also observe that the ascent is more marked with the kathode than with the anode.

Electrical connexions were established as shown in Diagram II.



The poles of a galvanic battery (*P.b.*) are connected with the commutator (C_1), provided with its cross wires; a commutator (C_3), without its cross wires being inserted between the battery and its commutator (C_1), and serving to direct the current from the secondary coil (*S.c.*) through the battery or through the resistance (R_1) not less than that of the battery.* The secondary coil (*S.c.*) is connected with the commutator (C_2). To the outer holes of the commutators (C_1, C_2) are connected the two electrodes (*E*, *E*). The inner holes of (C_1, C_2) are connected through a galvanometer (*G*) and a resistance (R_2).

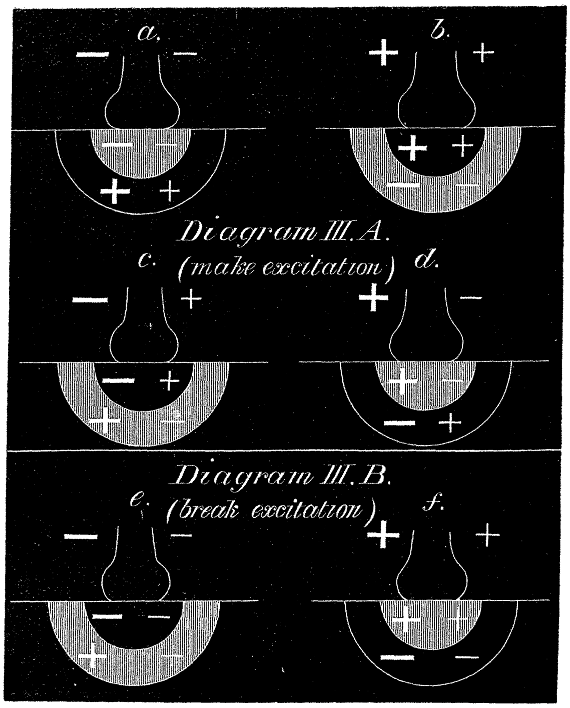
Either current can thus be reversed independently of the other by the commutators C_1, C_2, and the movable electrode can be made at will kathode or anode of the make or break induction current, with or without kathode or anode of the galvanic current.

The combinations possible are :—

Anode of the break induction current with				Anode of the galvanic current.			
Kathode	,,	,,	,,	Kathode	,,	,,	
Anode	,,	,,	,,	Kathode	,,	,,	
Kathode	,,	,,	,,	Anode	,,	,,	
Anode of the make induction current with				Anode of the galvanic current.			
Kathode	,,	,,	,,	Kathode	,,	,,	
Anode	,,	,,	,,	Kathode	,,	,,	
Kathode	,,	,,	,,	Anode	,,	,,	

These are schematically represented in the following diagram,—*III. A.* representing the conditions of make excitation, *III. B.* those of break excitation.

* We found, however, that this precaution may be safely dispensed with, the battery used being of low internal resistance.



The accompanying diagram represents the four polar combinations of the testing and polarising currents, and the coincidence of their respective kathodic and anodic regions. The signs in large type are intended to denote the kathode and anode of the polarising current, and the corresponding electrotonic states of the polar and peripolar regions. The signs in small type are intended to apply similarly to the testing current; "make," and "break" here refer to the commencement and cessation of a galvanic current, not to make and break induced currents, both of which give rise to make excitation. Figs. *a*, *b*, *c*. *d*, apply to the electrotonic modifications of the make excitation; figs. *e*, *f* to those of the break excitation; the region of excitation is in each case shaded in the diagram. The combinations are as follows:—

a. Polar excitation	coincides	with	polar katelectrotonus.	
b. Peripolar	„	„	peripolar	„
c. Peripolar	„	„	peripolar anelectrotonus.	
d. Polar	„	„	polar	„
e. Peripolar	„	„	peripolar	„
f. Polar	„	„	polar	„

A. *Polar alterations of excitability tested by the break induction current.*

Our first series of experiments were made with the ordinary arrangement of the coil (an electromotive force of 2 volts and a resistance of 1 ohm for the primary circuit), and gave the following results :—

1. *The effect of the kathode of the break induction current is greater than that of the anode.*

Our interpretation of this fact is as follows :—The current consists in an almost simultaneous make and break, and the stimulus depends on the former alone. With the kathode the polar region is kathodic, with the anode the peripolar region is kathodic; since the excitation proceeds in each case from the kathodic region, and since the current density is greater in the polar than in the peripolar region, the effect of the kathode is greater than that of the anode.

2. *The effect of the kathode of the break induction current is increased when that kathode is also kathode of the galvanic current.*

With the kathode of the induction current the polar region is kathodic, and excitation proceeds therefrom. With the kathode of the galvanic current the polar region is kathodic, and excitation proceeds from a region in which the excitability is increased. The effect is therefore increased.

3. *The effect of the anode of the break induction current is increased when that anode is also anode of the galvanic current.*

With the anode of the induction current excitation proceeds from the peripolar region. With the anode of the galvanic current that region is kathodic, and excitation proceeds from a region in which the excitability is increased. The effect is therefore increased.

4. *The effect of the kathode of the break induction shock is diminished when that kathode is also anode of the galvanic current.*

With the kathode of the induction current the polar region is kathodic, and excitation proceeds therefrom. With the anode of the galvanic current the polar region is anodic, and excitation proceeds from a region in which the excitability is diminished. The effect is therefore diminished.

5. *The effect of the anode of the break induction shock is diminished when that anode is also kathode of the galvanic current.*

With the anode of the induction current excitation proceeds from the peripolar region. With the kathode of the galvanic current that region is anodic, and excitation proceeds from a region in which the excitability is diminished. The effect is therefore diminished.

6. *The increase in the effect of the kathode of the break induction current when that kathode is also kathode of the galvanic current, is greater than the increase in the effect of the anode of the break induction current when that anode is also anode of the galvanic current.*

With the double kathode it is the polar region whence excitation proceeds and wherein excitability is increased; with the double anode it is the peripolar region whence excitation proceeds and wherein excitability is increased. The augmentation in the effect of a given stimulus is greater in the former case than in the latter because the density is greater.

7. *The diminution in the effect of the kathode of the break induction shock when that kathode is also anode of the galvanic current, is greater than the diminution in the effect*

of the anode of the break induction current when that anode is also kathode of the galvanic current.

With the combined induction kathode and galvanic anode the excitation and the diminished excitability are of the polar region with the combined induction anode and galvanic kathode, the excitation and the diminished excitability are of the peripolar region.

The diminution of a given effect is greater in the former case than in the latter. That diminution is such that the effect of the combined *faradic* anode and *galvanic* kathode is greater than that of the combined faradic kathode and galvanic anode. This fact was observed by BRÜCKNER, who saw in it a proof of electrotonus inasmuch as the previously more effective faradic kathode is rendered the less effective during the passage of an opposed galvanic current.

To the statements 1, 2, 3, 4, 6, 7 we have found no exception in all our experiments; statement 5, though expressing the usual event with currents of medium strength, requires qualification by this additional statement.

8. *With increasing strength of the galvanic current, the effect of the anode of the break induction current, when that anode is also kathode of the galvanic current diminishes to a minimum, and with further increase in the strength of the galvanic current increases up to and beyond the original normal.*

It is a constant phenomenon which is shown best with weak and moderate strengths of the induction current. We conjecture that it signifies extension of katelectrotonic influence in the previously anelectrotonic region (physiological) with increasing strength of the galvanic current. The increased excitability is in the polar region, the excitation is in the peripolar region in which excitability is diminished. But apart from its theoretical import, we lay stress on the fact as showing augmentation of excitability in the presence of opposed electromotive forces. We may observe further that with strong induction currents it does not appear, that with subminimal induction currents the increase is alone seen and only with greater strength of the galvanic current, and that exceptionally with induction currents of moderate strength the increase brought about by the galvanic current appears without previous decrease.

In seeking confirmation of the hypothesis applied to the fact expressed in the preceding statement, we were led to look for an analogous effect with the combined induction kathode and galvanic anode, and found ourselves entitled to qualify statement 4 by the following statement:—

9. *With increasing strength of the galvanic current, the effect of the kathode of the break induction current, when that kathode is also anode of the galvanic current, diminishes to a minimum, and with further increase in the strength of the galvanic current increases, but not up to the original normal within endurable strength of the galvanic current.*

After several failures we verified this statement with moderate strength of the induction current. It is the converse of the preceding observation, and our interpretation is likewise a supposition that the phenomenon signifies invasion of katelectrotonic by anelectrotonic region (physiological) with increasing strength of the galvanic current. The increased excitability is in the peripolar region, the excitation is in the polar region in which excitability is diminished. The difficulty with which this phenomenon is brought into evidence, in comparison with its converse, is accounted for by the supposition that in the converse case we have to deal with the invasion of peripolar anelectrotonic by polar katelectrotonic region, and in the present case with invasion of polar anelectrotonic by peripolar katelectrotonic region. The difficulty is due to the pain caused by the strong galvanic current required, and to the tetanus which such a current evokes, so that the increase appears only when the conditions are exceptionally favourable to electrical density in the peripolar region as compared with density in the polar region; we noticed in effect that when this increase was brought about, kathodic polarization of increasing strength effected increase in the effect of the induction anode without preceding diminution. The difference between the augmentation of the faradic anode under the influence of the galvanic kathode and that of the faradic kathode under the influence of the galvanic anode may be formally stated as follows.

10. *The increasing effect of the combined faradic anode and galvanic kathode takes place with a weaker galvanic current than that of the combined induction kathode and galvanic anode; the increase is greater and more rapid in the former case than in the latter.*

We record finally, under these statements relating to the break induction current, an observation relating to the make induction current, because it was a salient feature in our experiments with the ordinary arrangements of the coil, and because its mention emphasises the superiority of the kathode of the make induction current combined with the kathode of the galvanic current, over all other combinations of the two poles.

11. *With the ordinary arrangement of the coil used there was no contraction to the make induction current with all combinations and all strengths of the induction and galvanic currents, except the combined anode of the break induction current* (i.e., *kathode of the make induction current*) *and kathode of the galvanic current.*

The interpretation of this fact is identical with that for the kathode of the break induction current when also kathode of the galvanic current. Excitation thus coincides with increased excitability in the polar region.

B. *Polar alterations of excitability tested by the make induction current.*

In order to use make induction currents as the test of excitability, we modified the coil after the method of Henry, using 30 Leclanché cells and a resistance of 100 ohms in the primary circuit; the results differed in no respect from the results previously obtained with break induction currents, and it is therefore only necessary to add that we have verified all the above statements for the make as well as for the break induction current (with the exception of statement 9, which we did not attempt to verify).

Using the following abbreviations,

F— for the effect of the kathode of the induction current (make or break).
F+ ,, ,, anode ,, ,, ,,
G— for polarisation by the galvanic kathode.
G+ ,, ,, ,, anode.

the above results may be summed up thus :—

			Tracings:
(1)	F—	> F+	—
(2)	F— with G—	> F—	14, 20
(3)	F+ with G+	> F+	19
(4)	F— with G+	< F—	17, 18, 13*b*
(5)	F+ with G—	$\lesseqgtr$ F+	13*a*, 16
(6)	Increase of F— with G—	> Increase of F+ with G+ . .	19 to 22
(7)	Diminution of F— with G+	> Diminution of F+ with G— .	23 and 24
(8)	F+ with increasing G— is at first diminished, then increased to above normal		13*a*
(9)	F— with increasing G+ is at first diminished, then begins to increase		13*b*
(10)	The increase from minimum F+ with G— occurs with weaker G than that from minimum F— with G+. With further increase of G it is greater in the case of F+ with G— than in that of F— with G+		13*a*, *b*

For convenience of reference we have given with each of the above statements a number referring to an illustrative figure.

C. *Minimum exciting strength of an induction current with increasing strength of a polarising current.*

The following tables contain numbers expressing in millimetres the distance of the secondary coil at which contractions were first marked on the cylinder in the absence of polarisation, and in the presence of polarisation by 10 and 20 cells respectively.

Induction pole.	Distance of coil.		Number of cells of polarising current.	
F+	113	113	0	G+
,,	117	120	10	,,
,,	135	140	20	,,
F−	117	115	0	G−
,,	131	122	10	,,
,,	151	155	20	,,
F+	113	113	0	G−
,,	111	116	10	,,
,,	112	112	20	,,
F−	118	118	0	G+
,,	108	110	10	,,
,,	103	104	20	,,

These numbers agree with the conclusions already obtained, but this method is less satisfactory than the graphic method; the determination of the minimum F+G− is especially variable, as indeed might have been expected from our previous results.

D. *Proof of the physiological nature of the interference when faradic and galvanic currents in one circuit are opposed in direction.*

It has been shown by one of us* that the latent time of the break contraction on Man far exceeds that of the make contraction. That the length of this period depends on a persistence of anelectrotonus after its galvanic provocative has ceased was proved by showing that the recovery of a faradic tetanus, interfered with by anodal polarisation for a given time, does not occur within a period equivalent to a make latency, but is delayed for a period equivalent to a break latency. The existence of this period of delay is proof of physiological versus physical interference. From this datum it can be shown that the diminution of effect when the two currents are opposed is always anelectrotonic, whether the combined exploring pole be faradic kathode with galvanic anode or faradic anode with galvanic kathode, for in either case the period of persistence of anelectrotonus is observed.

The following experiment constitutes the easiest demonstration of electrotonus on Man; it is an old experiment, but has not hitherto received a physiological interpretation:—

Holding in both hands the poles of a secondary coil with vibrating interrupter, so that both arms are tetanised, it may be observed with suitable distance of coil and

* A. WALLER, in an oral communication to the Physiological Society of London, November, 1881. (Arch. de Physiologie, Avril, 1882.)

strength of galvanic current that a given tetanus is greatly increased, or that previously ineffectual stimuli tetanise when a galvanic current traverses the coil in the same direction as that of the break induction current; and, conversely, that a tetanus is greatly weakened or abolished when a galvanic current traverses the coil and body in the opposite direction to that of the break induction current. With the two currents in the same direction, all induction kathodes in the body coincide with galvanic kathodes, and the increased effect is katelectrotonic; with the two currents in opposite directions, all induction kathodes in the body coincide with galvanic anodes, and the diminished effect is anelectrotonic. The latter statement is proved by showing that the interference is physiological, inasmuch as the time which elapses between the removal of the galvanic current and the contraction produced by the released *faradic* excitation is greater than a make latency, and may be as long as a break latency. From this it is a legitimate inference that the former statement is also true (Tracing 25).

II. Polar Alterations of Excitability during the passage of a Galvanic Current tested by makes and breaks of a Galvanic Current.

Preliminary.—Before using the make and break of a galvanic current as the test of alterations during and after the passage of an uninterrupted galvanic current in the same circuit, we examined the series of effects of the former alone. As was to be expected, this test showed more marked variations than had been found with induction currents. The full discussion of the alterations with time and current strength of the excitability during and after galvanisation demands however prolonged investigation, and will form the subject of a separate paper. We shall only anticipate upon that part of the question sufficiently to justify certain statements.

We observe that a horizontal series of make contractions, with equal duration and interval of current, can be converted into an ascending series by using a stronger current, or by altering the excitation rhythm to one of short duration and long intervals; that, conversely, a horizontal series can be converted into a descending series by using a weaker current, or by altering the excitation rhythm to one of long duration and short interval.

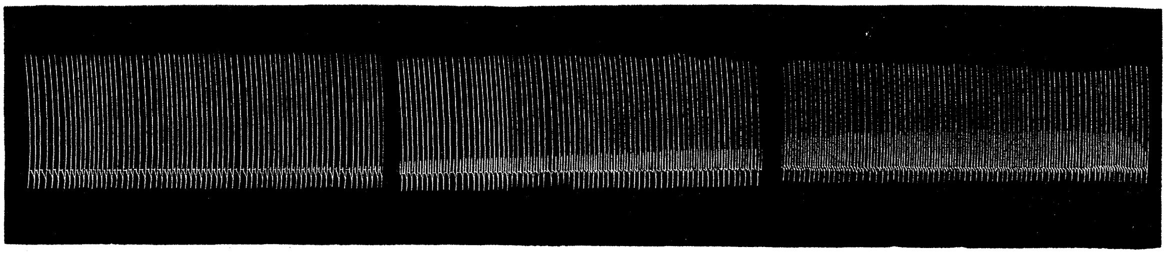
We shall show, when we come to treat of the after-effects, that excitability after kathodal polarisation is at first diminished, subsequently increased (Tracings 8, 34). We also borrow an observation from a future paper on which we base the statement that this diminution of excitability increases in degree and in duration up to a certain limit of strength and duration of polarisation, and that beyond that limit it diminishes and sooner gives place to a more marked increase of excitability. Upon these data we base the statements that descending series indicate that each make excitation occurs during the period of diminished excitability consequent on previous make, and that ascending series indicate that each make excitation occurs during increased excitability consequent on previous make.

We also observe that at the termination of an ascending series a weaker current than the original current will cause a greater contraction than at first; that at the termination of a descending series a stronger current than the original current will cause a smaller contraction than at first. These facts indicate in the former case diminution of increased excitability, in the latter case a summation of diminished excitability which however very rapidly gives way to increase.

We notice that, *cæteris paribus*, ascending series are most frequently observed at the beginning of experiments (independently of any increase of current strength), that descending are most frequently observed after the nerve has been for some time subjected to experiment. This probably signifies that increased excitability is more apparent before the general excitability has been raised, diminished excitability while the general excitability is raised above normal, and we shall give an observation to show that the excitability is raised above the normal, and so remains for a considerable period after polarisation (Tracing 32).

We observe finally that anodic opening contractions at first increase, then gradually diminish, and that it requires far stronger or more prolonged currents to produce the opening contraction at the end than at the beginning of the experiment.

Tracing A.

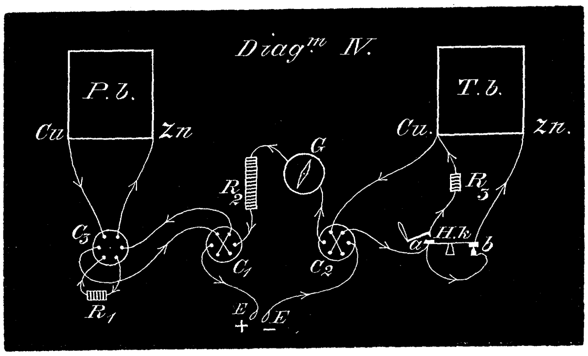


Series of anodic closure and opening contractions by 150 cells (17 milliwebers), 9000 ohms additional resistance in circuit. The interruptions in the tracing represent periods of about $2\frac{1}{2}$ minutes each during which the opening contractions gradually diminished.

Amidst complex conditions of time, current-strength, and excitability, various results are naturally to be expected, and it is to be borne in mind that gradual alterations of current-strength, by alteration of resistance and by polarisation currents, will adulterate the developing changes of excitability (vide pp. 980, 981). On this account we had recourse to the introduction of a considerable additional resistance in order to dilute the effects of physical change, and to disengage, as far as possible, physiological changes from the physical adulteration. All things considered, we concluded that *a descending series, with an excitation rhythm, which previously gave a horizontal series, signifies decreasing excitability; that, conversely, an ascending series indicates increasing excitability; declining excitability is proved* à fortiori *when, with constant current-strength and excitation rhythm, a previously ascending series is con-*

verted into a descending series; increasing excitability when a previously descending series is converted into an ascending series.

Tracing 26 shows that it is not indifferent whether make and break of a galvanic current be effected in the principal circuit, or in a deriving metallic circuit.



Electrical connexions were established as in Diagram IV.; they are substantially the same as in Diagram II. with the substitution of a battery *T.b.* for the coil *S.c.*, and with the addition of a HELMHOLTZ' key (*H.k.*) so arranged that the current of *T.b.* can be added to or subtracted from the current of *P.b.* without breaking circuit and without short circuiting *T.b.* for any appreciable period. By reference to the diagram it will be understood that the make and break of *T.b.* occur at the end *a* of the key; by depressing the handle *T.b.* is bridged at *a*, and its current cut off, further short circuiting being prevented by the instantly succeeding break at *b*. By raising the handle the bridge is re-established at *b*, and instantly after broken at *a*, so that the current is made. The two inferior surfaces at *a* and *b* are connected; a resistance R_3, not less than that of the battery *T.b.* being introduced between the battery and the upper surface of the side *a* of the key, so that the current of *P.b.* be not transferred to a path of less resistance when the testing battery is cut out of circuit. This resistance was only used unfavourably to the results anticipated, viz.: in examining for increased excitability during polarisation; but its use was found to be a superfluous precaution as had been found for the resistance R_1.

We always used the two galvanic currents in the same direction, hence we obtained by the above arrangement a comparison of the effects of a given current with the effects of the same current added to or subtracted from a pre-established current, viz.:

Anodic make alone or added to an anodic current.
Kathodic ,, ,, a kathodic ,,
Anodic break alone or subtracted from an anodic current.
Kathodic ,, ,, a kathodic ,,

The experiments on which the following statements are based, were made with 11,000 ohms additional resistance in circuit:—

1. *The effect of kathodic make is greater than that of anodic make.*

With the kathode, the polar region is kathodic; with the anode, the peripolar region is kathodic. The make excitation proceeds from the kathodic region, and the current density is greater in the polar than in the peripolar region; the effect at make of the kathodic is therefore greater than that at make of the anode.

2. *The effect of anodic break is greater than that of kathodic break.*

With the anode, the polar region is anodic; with the kathode, the peripolar region is anodic. The break excitation proceeds from the anodic region, and is greater when it is polar than when it is peripolar.

3. *The effect of kathodic make is increased during the flow of a kathodic current.*

Kathodic excitation and kathodic increased excitability are both of the polar region, and the effect is therefore greater with than without the kathodic current.

4. *The effect of anodic make is increased during the flow of an anodic current.*

Kathodic excitation and kathodic increased excitability are both of the peripolar region.

5. *The effect of anodic break is diminished during the flow of an anodic current.*

With the anode of the testing current the break excitation proceeds from the polar region which is anodic, and in which anodic influence is maintained by the remaining current. The break excitation thus falls on a region in which the excitability is depressed, and its effect is diminished or abolished.

6. *The effect of kathodic break is diminished during the flow of a kathodic current.*

The break excitation falls on the peripolar region in which the excitability is depressed by the anodic influence of the remaining current.

7. *The increase in the effect of kathodic make during the flow of a kathodic current is greater than the increase in the effect of an anodic make during the flow of an anodic current.*

The kathodic increase is greater when it is polar than when it is peripolar, *i.e.*, greater with the double kathode than with the double anode.

8. *The diminution in the effect of anodic break during the flow of an anodic current is greater than the diminution in the effect of kathodic break during the flow of a kathodic current.*

The anodic diminution of excitability is greater when it is polar than when it is peripolar, *i.e.*, the diminution is greater with the double anode than with the double kathode.

Using the following abbreviations :—

K.C.C.	for the	kathodic closure contraction.		
A.C.C.	,,	anodic	,,	,,
K.O.C.	,,	kathodic opening		,,
A.O.C.	,,	anodic	,,	,,
K.D.	,,	kathodic current duration.		
A.D.	,,	anodic	,,	,,

the above results may be thus summed up :—

1. K.C.C. > A.C.C.
2. A.O.C. > K.O.C.
3. K.C.C. during K.D. > K.C.C.
4. A.C.C. during A.D. > A.C.C.
5. A.O.C. „ A.D. < A.O.C.
6. K.O.C. „ K.D. < K.O.C.
7. Increase of K.C.C. with K.D. > Increase of A.C.C. with A.D.
8. Diminution of A.O.C. with A.D. > Diminution of K.O.C. with K.D.

These statements are illustrated in Tracings 35 and 36, with the exception of statements 6 and 8, which we have verified, but of which it is difficult to obtain a good record.

Minimum Exciting Strength of a Galvanic Current Added to or Subtracted from a Pre-existing Galvanic Current.

We determined the strength of current necessary to produce minimum contraction with polarising currents of increasing strength. The experiments were made on the peroneal nerve, with and without additional resistance in circuit, and are embodied in the following table :—

First appearance on tracing of	Number of cells of testing current. (without additional resistance.)			Number of cells of polarising current.
	a.	*b.*	*c.*	
K.C.C. . . .	9	9	7	0
	8	8	..	2
	7	7	5	4
	6	6	..	6
	5	5	3	8
	4	4	..	10
	3	3	2	12
	3	3	..	14
	2	2	..	16
A.C.C. . . .	10	10	9	0
	8	9	..	2
	8	8	7	4
	7	7	..	6
	6	6	5	8
	5	5	..	10
	4	4	4	12
	3	3	..	14

First appearance on tracing of	Number of cells of testing current. (with 1700 ohms additional resistance.)			Number of cells of polarising current.
	a.	*b.*	*c.*	
A.O.C. . . .	14	12	12	0
	16	14	14	2
	18	16	20	4
	22	20	24	6
	28	24	28	8
	30	26	..	10
K.C.C. . . .	20	19	23	0
	19	18	..	2
	18	18	..	4
	18	17	..	6
	17	16	20	8
	16	15	..	10
	14	14	..	12
	13	13	..	14
	13	12	15	16
	12	11	..	18
	11	10	..	20
	10	10	12	22
	10	9	..	24
	9	9	..	26
	9	8	..	28
	..	..	9	32
A.C.C. . . .	17	17	15	0
	15	16	..	2
	15	15	..	4
	13	13	..	6
	12	12	12	8
	10	10	..	10
	10	10	..	12
	9	9	..	14
	9	8	8	16
	8	8	..	18
	..	..	5	24
	..	..	3	32

N.B.—The figures in columns *a* and *b* were taken on the same day, those in column *c* on another occasion. The minimum stimulus of the A.C.C. is the most uncertain.

This table shows that alterations of excitability increase with the strength of the polarising or pre-existing current, and justifies the statement that :—*The greater the density of pre-existing current, the smaller the increase of density, and the greater the decrease of density necessary to effect stimulus.*

Tracings 35 and 36 illustrate the statement that :—*The greater the density of pre-existing current, the greater the excitatory effect of a given increase of density, the less the excitatory effect of a given diminution of density.*

III. Polar Alterations of Excitability tested by Mechanical Excitation.

In order to ensure the coincidence of excitation with polar alteration of excitability, we used the electrode itself as the medium of mechanical excitation. We have found only one point of the body which lends itself to the mechanical excitation of nerve, viz., the elbow, at the place where the ulnar nerve runs immediately under the skin upon a resisting bony groove. Here it is possible, though not always easy, to elicit regular contractions by striking a small electrode held steadily over the nerve, with gentle and regular blows of an ordinary hammer. The test may appear a rough one, but the results are sufficiently uniform and evident to leave no doubt of the reality of the alterations.

When the kathode rests on the nerve, the polar region being therefore kathodic, the effect of mechanical excitation is increased; when the anode rests on the nerve, the polar region being therefore anodic, the effect of mechanical excitation is diminished or abolished.

On breaking the current the contractions appear in both cases greater than before.

A possible objection must be forestalled. It might be said that the increased effect during the kathodic current, is partly due to the change of *density* in the current, arising from the sudden compression of the tissues lying between the electrode and the nerve. This is not consistent with the fact that such a change of *density* would increase the contractions when a strong polarising anode is applied, whereas the contrary is observed. We may also remark that the effects are equally well observed with a large additional resistance in circuit.

IV. Polar Alterations of Excitability Subsequent to the Passage of the Galvanic Current.*

Preliminary.—Before drawing conclusions as to the state of excitability after the passage of the galvanic current, it is necessary to realise the possible influence of polarisation currents and alterations of resistance upon the current-strength.

* The after-effects have been alluded to by some of the authors quoted above (Eulenburg, Samt). They form the subject of a laborious inquiry by Remak ("Ueber Modificirende Wirkungen Galvanischer

Changes of current-strength depend upon various conditions which we have not been able to determine satisfactorily for the want of a sufficiently delicate galvanometric record. Pending such a determination, which will be necessary when we come to the investigation of the time factor in electrotonic and post-electrotonic processes, we record the alterations which we have hitherto observed. When the electrodes are first applied the current grows gradually to a maximum, owing to the permeation of the skin with moisture, and, perhaps, to the accompanying vascular turgidity. On applying the electrodes to the skin previously prepared by soaking, the current at once reaches a maximum from which it declines at first rapidly, then more and more slowly. On renewed make of the same current instantly after interruption the galvanometer shows that the current has not recovered its strength. On renewed make after another interruption of 30–60 seconds the galvanometer indicates that the current has recovered. If a current that has been allowed to flow until the galvanometer needle has ceased to fall is suddenly reversed, the current-strength is indicated to be greater in the new direction. These effects are such as would be produced, at least partially, by polarisation of the electrodes, and that this is so can be shown in the usual way by leaving the electrodes only connected with the galvanometer, either in direct contact with one another, or with the body intervening. Current is indicated in either case, greater of course in the former. We observe another fact indicating a fallacy to which the estimation of after-effects is especially liable, viz.: that after a given duration of current, with a given deflection of the needle, a given interval is followed by a greater deflection which rapidly subsides to the original deflection—a phenomenon which may repeat itself several times in succession, and obtains whether the electrodes are kept in broken or in closed circuit during the interval. Without committing ourselves to any positive statement, we may remark that our observations led us to suppose that during the passage of the galvanic current, an opposed electromotive force is developed within the body which rapidly subsides. But however this may be, the importance of these alterations of current-strength as a source of fallacy are obvious, and they especially concern the question of after-effects. We have not been able as yet to assign to them their exact share for and against the manifestation of the after-effects. But we have, we think, succeeded in demonstrating the rough facts in spite of the fallacy, and it will be one of the objects of a future paper to find numerical expression for this vague quantity.

Finally we may mention a further possible source of error, which however cannot be eliminated should it exist, viz.: the unequal alteration by the current of the conductivity of the nerve and of the surrounding tissues. It is conceivable that the conductivity of the surroundings of nerve should be increased in a greater proportion than

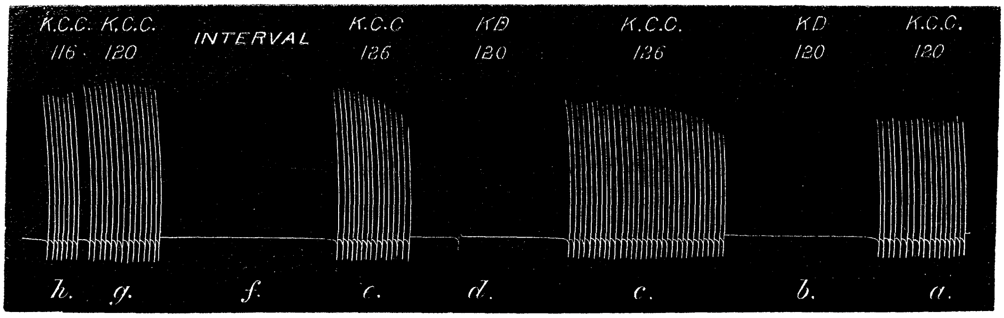
Ströme," &c. Deutsches Archiv f. Klin. Med., 1876, p. 264). He lays stress upon the fallacies arising from alterations in the current-strength, and used the galvanic test only. He states that K.C.C. is increased after K.D., and variable after A.D.; that A.C.C. is increased after K.D., and variable after A.D. He does not seem to have determined any alteration of the opening contraction.

that of the latter, being more vascular and susceptible, therefore of greater increase of vascularity under the influence of the current.

We made the conditions of experiment unfavourable to the results anticipated by using a weaker current than the original current when it was desired to prove augmentation of excitability, a stronger current than the original current when it was desired to prove diminution of excitability. This was done for the galvanic test by altering the number of cells so that the galvanometer deflection was evidently smaller or greater than before. The instruments at our disposal did not allow us to apply this *à fortiori* device to all the cases of the question, but we established our principal results by its means, and we think that the proof of these may be taken to cover the remaining cases of which the results are congruent.

Tracing B, with the accompanying description, are given as formal examples of the application of this proof as regards the polar region. Tracings C and D illustrate a simpler and more direct proof of the physiological nature of the after-kathodic change.

Tracing B.

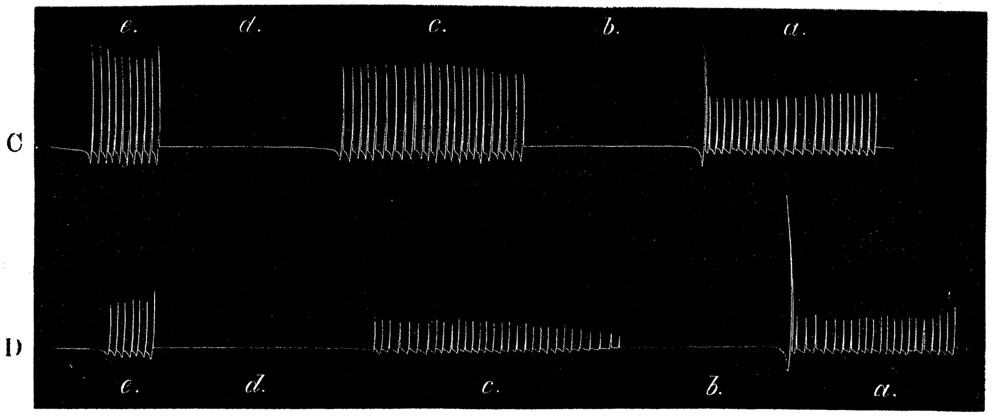


Tracing B. 11,000 ohms additional resistance in circuit.

	Cells.
a. K.C.C.	120
b. K.D.	120
c. K.C.C.	126
d. K.D.	120
e. K.C.C.	126
f. Interval.	
g. K.C.C.	120
h. K.C.C.	116

The contractions at (*e*) with stronger current are smaller than those at (*a*); therefore the excitability is diminished. The contractions at (*h*) with weaker current are greater than those at (*a*); therefore the excitability is increased.

Tracings C and D.



Tracing C. 750 ohms additional resistance.

		Cells.	m.w.
a.	K.C.C.	12	5
b.	K.D.	28	13
c.	K.C.C.	12	5·5
d.	Interval.		
e.	K.C.C.	12	5·5

Tracing D. 5000 ohms additional resistance.

		Cells.	m.w.
a.	K.C.C.	30	5
b.	K.D.	70	13
c.	K.C.C.	30	5
d.	Interval.		
e.	K.C.C.	30	5

The comparison of series (*c*) in the two preceding figures shows that unless a considerable resistance be added in circuit, the after-kathodic diminution may be masked owing to an increase of current-strength.

The following statements (the letters have the same meaning as at page 972) summarise the results of our experiments on the peroneal nerve, with the precautions taken of an approximate galvanometric control and of an additional resistance of from 10,000 to 20,000 ohms in circuit. This being about six to twelve times the resistance of the body, the possible effects of physical change were divided by so much, and the effects of altered excitability practically disengaged from the fallacy. The cases in which we have proved *à fortiori* the physiological nature of the change are marked with an asterisk (*) in table of after-effects by the galvanic test.

After-effects tested by the Induction Current.

1. F+ after G+ is less than before.
2. F− after G− is less ,,
3. F+ after G− is greater ,,
4. F− after G+ is greater ,,

That is to say: *kathodic excitation of a given region produces less effect after than before kathodic polarisation, greater effect after than before anodic polarisation.*

5. The diminution of F− after G−	is greater than	the diminution of F+ after G+
6. The increase of F− after G+	is greater than	the increase of F+ after G−

That is to say: *the after-kathodic diminution and the after-anodic increase are more marked in the polar than in the peripolar region.*

These statements are illustrated in Tracings 15–20. They refer to the immediate after-effects, *i.e.*, those manifest within the first few seconds after polarisation has ceased, and we must add the statement that *the after-anodic increase is of long duration, the after-kathodic diminution soon gives way to an increase of long duration* (Tracing 34).

After-effects tested by the Galvanic Current.

	Immediately.	Subsequently.	
1. K.C.C. after K.D. is	less*	greater*	than before polarisation.
2. K.O.C. ,, K.D. ,,	greater	?	,, ,,
3. A.C.C. ,, A.D. ,,	less*	greater*	,, ,,
4. A.O.C. ,, A.D. ,,	greater*	less*	,, ,,
5. K.C.C. ,, A.D. ,,	greater	greater	,, ,,
6. K.O.C. ,, A.D. ,,	less	?	,, ,,
7. A.C.C. ,, K.D. ,,	greater	greater	,, ,,
8. A.O.C. ,, K.D. ,,	less	less	,, ,,

That is to say: *kathodic excitation produces less effect after than before kathodic polarisation, greater effect after than before anodic polarisation.*

9. The diminution of K.C.C. after K.D.	is greater than	the diminution of A.C.C. after A.D.
10. The diminution of A.O.C. after K.D.	is greater than	the diminution of K.O.C. after A.D.
11. The increase of A.O.C. after A.D.	is greater than	the increase of K.O.C. after K.D.
12. The increase of K.C.C. after A.D.	is greater than	the increase of A.C.C. after K.D.

That is to say: *the after-kathodic diminution and the after-anodic increase are more marked in the polar than in the peripolar region.*

These statements, with the exception of 2 and 6 referring to the K.O.C., and consequently also of 10 and 11, are illustrated in Tracings 28–31. They refer to the immediate after-effects.

We are not at present in a position to discuss the subsequent after-effects, which we reserve until we shall have investigated the *course* of electrotonic and post-electrotonic changes. We cannot, however, omit drawing attention to the peculiarity affecting the opening excitation, which constitutes an exception to the rule that the subsequent after-effect of polarisation of either sign is increased excitability. The subsequent after-effect of anodic polarization as tested by anodic break is apparently diminished excitability, yet by testing in the polar region by kathodic make, evidence of increased excitability is obtained when the effect of the original anodic break may be almost lost. To what specific difference in the excitatory process at make and at break this may point we cannot conjecture, and we have only to remark that the fact is of the same nature as the gradual diminution of successive anodic break contractions.

Description of Tracings.

(N.B.—All Tracings, except Tracing 25, are to be read from right to left. The cylinder speed is about 2 centims. per minute.)

Tracings 1–7. Series of kathodic closure contractions with different strength and rhythm of current. 13,000 ohms in circuit.

	Strength. Cells.	Strength. m.w.		Duration of flow.	Duration of interval.
Tracing 1.	75	4	1st part	3″	1″
			2nd part	1″	3″
Tracing 2.	150	9	1st part	1″	3″
			2nd part	3″	1″
Tracing 3.	150	9		3″	1″
Tracing 4.	75	4		1″	3″
Tracing 5.	75	4		2″	2″
Tracing 6.	150	9		2″	2″
Tracing 7.	75	4		2″	2″

In support of the argument that descending series indicate that make excitation occurs during the diminished excitability consequent on previous make, ascending series that it occurs during the increased excitability consequent on previous make, we may refer to Tracings 1 and 2, in which the rhythm was reversed in the course of each series. The comparison of Tracings 6 and 7 shows, we believe, that the period of diminution is longer with the weaker than with the stronger current. Tracing 4 as compared with Tracing 5 shows diminution of the descent by prolonging the interval and shortening the duration of flow; we suppose that the make excitation in the former case does not, as in the latter, coincide in time with a state of diminished excitability.

Tracing 3 as compared with Tracing 6 shows diminution of the ascent by shortening the interval and prolonging the duration of current; we suppose that in the former case, as compared with the latter, the make excitation falls within a period of diminished excitability.

Tracings 8–14 show the effect of the induction current modified by a galvanic current in the same circuit; without additional resistance.

Tracing 8. Break induction kathodic contractions before, during, and after passage of a galvanic current in the same direction. Distance of coil 10 centims. Galvanic current of 12 cells.

Tracing 9. Break induction anodic contractions before, during, and after passage of a galvanic current in the same direction. Distance of coil 9 centims. Galvanic current of 12 cells.

Tracing 10. Break induction kathodic contractions before, during, and after passage of a galvanic current in the opposite direction. Distance of coil 9·5 centims. Galvanic current of 4 cells.

Tracing 11. Break induction anodic contractions before, during, and after the passage of a galvanic current in the opposite direction. Distance of coil 7 centims. Galvanic current of 12 cells.

Tracing 12. Series of contractions by the break induction kathode, with increasing strengths of current. The figures accompanying each group of contractions denote the distance in centims. of secondary from primary coil.

Tracing 13. Effect of break induction anode with increasing strength of an opposed galvanic current. The first group of five contractions is taken in the absence of any galvanic current, the 2nd group with a galvanic current of 2 cells, the 3rd with 4 cells . . . , the 21st with 40 cells (19 milliwebers). Distance of coil 6 centims. 1000 ohms additional resistance in circuit.

Tracing 13*b*. Effect of break induction kathode with increasing strength of an opposed galvanic current. The first group of three contractions is taken in the absence of galvanic current, the 2nd group with 2 cells, the third with 4 cells . . . , the 15th with 28 cells. Distance of coil 8 centims. No additional resistance in circuit.

Tracing 14. Series of make and break induction contractions, with and without galvanic current in circuit. HENRY's modification (E. M. F. of 30 volts; 100 ohms in primary circuit). Reading from right to left the first of each pair of contractions is by the make, the second by the break current. 1000 ohms added in circuit.

a.	Make induction anode	and	break induction kathode.	
b.	Make induction kathode	,,	break induction anode.	
c.	Make induction anode with galvanic kathode	,,	break induction kathode with galvanic kathode.	
d.	Make induction kathode with galvanic anode (abolished)	,,	break induction anode with galvanic anode.	
e.	Make induction anode with galvanic anode	,,	break induction kathode with galvanic anode.	abolished
f.	Make induction kathode with galvanic kathode	,,	break induction anode with galvanic kathode.	

Tracings 15–20: Illustrate the same facts as Tracings 8–11, and show more clearly the after-effects. 11,000 ohms additional resistance in circuit.

	Induction current.	Distance of coil. centims.	During.	After.	Galvanic current, 50 cells (3·5 m.w.).
Tracing 15.	—	4	increased	diminished	—
Tracing 16.	+	0	diminished	increased	—
Tracing 17.	—	5	diminished	increased	+
Tracing 18.	—	0	diminished	increased	+
Tracing 19.	+	0	increased	diminished	+
Tracing 20.	—	5	increased	diminished	—

The greater increase of F — by G — than of F + by G + is seen in the comparison of Tracing 19 with Tracing 20; the greater diminution of F — by G + than of F + by G — in the comparison of Tracing 10 with Tracing 11.

The diminution of F — after G — (Tracings 8, 15, 20); the diminution of F + after G + (Tracing 9); and the superiority of the former over the latter are also to be recognised in Tracings 15–20 especially. Likewise the increase of F — after G + (Tracing 17), the increase of F + after G — (Tracing 18), and the superiority of the former over the latter. The make induction contraction is seen in Tracing 11.

Tracings 21–24 show the effect of the break induction current with increasing strength of a galvanic current in the same circuit. No additional resistance in circuit.

Tracing 21. Induction kathodic contractions with increasing galvanic current in the same direction. The first group of five contractions is taken in the absence of galvanic current, the second with a current of 2 cells . . ., the last with a current of 20 cells. (In the next three tracings the galvanic current is increased as in this by 2 cells with each successive group.) Distance of coil 10·5 centims.

Tracing 22. Induction anodic contractions with increasing galvanic current in the same direction. Distance of coil 9 centims.

Tracing 23. Induction kathodic contractions with increasing galvanic current in the opposite direction. The contractions are much reduced with 4 cells, abolished with 6 cells. Distance of coil 9·5 centims.

Tracing 24. Induction anodic contractions with increasing galvanic current in the opposite direction. The contractions decrease as the current increases to 12 cells, increase as the current increases from 14 cells. Distance of coil 8 centims.

Tracing 25. The upper line shows the latency of three coinciding contractions by closure of the galvanic current through both arms. The small vertical line marks the instant of excitation.

The lower line shows the interval between the instant of removal of the galvanic current and contraction by excitation by the (physiologically) released faradic current, the poles being for the arm explored *anode galvanic* and *kathode break faradic*. Three contractions coincide.

The middle line shows the same latency with the poles reversed, these being for the arm explored *kathode galvanic* and *anode break faradic.*

The closure latency (upper line) is determined in the usual way by a catch fixed to the cylinder. The liberation interval (two lower lines) is determined by causing a metal surface fixed to the cylinder to short-circuit the galvanic current for a given period, thus subtracting it from the combined faradic and galvanic circuit. The contractions registered are taken from the right forearm. The interruptions of the inducing current are made by a reed vibrating 200 per second. A chronograph records 100 vibrations per second below the tracing.

Tracing 26. The two groups are kathodic closure contractions by 10 cells (6 milliwebers). 1000 ohms' resistance in circuit. For the group of contractions to the right the closure excitations were made by bridging a break in the principal circuit; for the group to the left by breaking a bridge in a deriving metallic circuit.

Tracing 27. The two groups are anodic closure and opening contractions by 30 cells (23 milliwebers), 1000 ohms in circuit. For the group to the right the closure excitations were made by bridging a break in the principal circuit, the opening excitations by breaking a bridge in that circuit; for the group to the left the closure excitations were made by breaking a bridge in a deriving metallic circuit, the opening excitations by bridging such a break.

The tracings show that a stronger make excitation is obtained by closing a key in the principal circuit than by opening a key in a deriving metallic circuit, and that a stronger break excitation is obtained by closing a key in a deriving metallic circuit than by opening a key in the principal circuit. The effects of excitation made in these two ways must not therefore be compared.

Tracings 28–31 show series of contractions by make and break of a galvanic current before and after the passage of a galvanic current in the same and in the opposite direction for 1 minute. Each series lasts 1 minute. Duration of testing current, 1 second; interval, 2 seconds.

Tracing.	Testing current.	Resistance in circuit.	Number of cells.	Milli-webers.	Polarising current.	Resistance in circuit.	Number of cells.	Milli-webers.	After effect.
28	K.C.C.	13,000	70	3	An.	13,000	150	9	Increase
29	K.C.C.	,,	,,	,,	Kat.	,,	,,	,,	Diminution
30	A.C.C.	8000	110	11	,,	8000	110	11	Increase
	A.O.C.	,,	,,	,,	,,	,,	,,	,,	Diminution
31	A.C.C.	,,	,,	,,	An.	,,	,,	,,	Diminution
	A.O.C.	,,	,,	,,	,,	,,	,,	,,	Increase

The greater diminution of K.C.C. after K.D. than of A.C.C. after A.D. may be recognised by comparing Tracings 29 and 31.

The greater increase of K.C.C. after A.D. than of A.C.C. after A.D. may be recognised by comparing Tracings 28 and 30.

Tracing 31 shows the diminution of A.O.C.

Tracing 32 shows the effect of the addition of resistance in the secondary circuit on the response to the break induction kathode and anode respectively. The first group (reading from right to left) is a series of kathodic contractions, the second group is a series of anodic contractions without added resistance. The third group is a series of kathodic, the fourth a series of anodic contractions with 1000 ohms added resistance. The fifth and sixth groups are taken with 2000 ohms added resistance, the anode group being only just visible. On further additional resistance the anode ceased to produce any effect. The seventh group is a series of kathodic contractions with 3000 ohms added. The eighth group (barely visible) is a series with 4000 ohms. With 5000 ohms the kathode ceased to produce any effects. Distance of coil 9 centims.

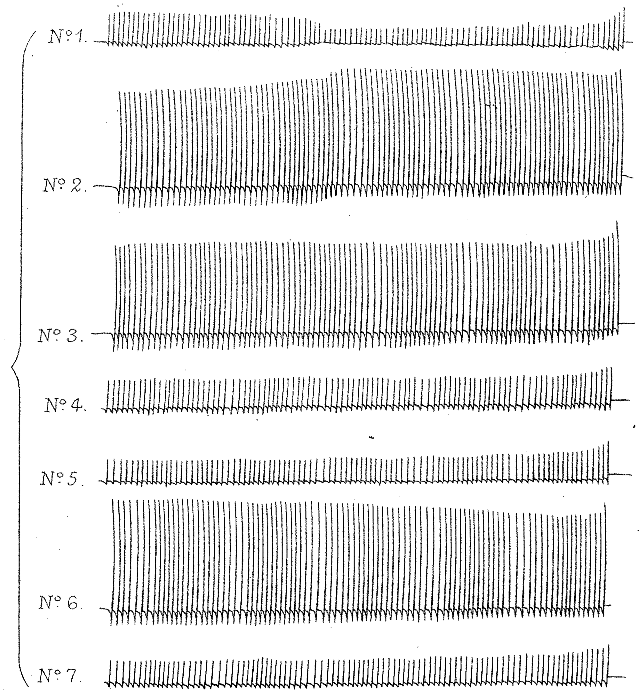
Tracing 33 shows the gradual appearance of contraction with the make (kathodic) and break (anodic) induction currents of gradually increasing strength. HENRY'S modification.

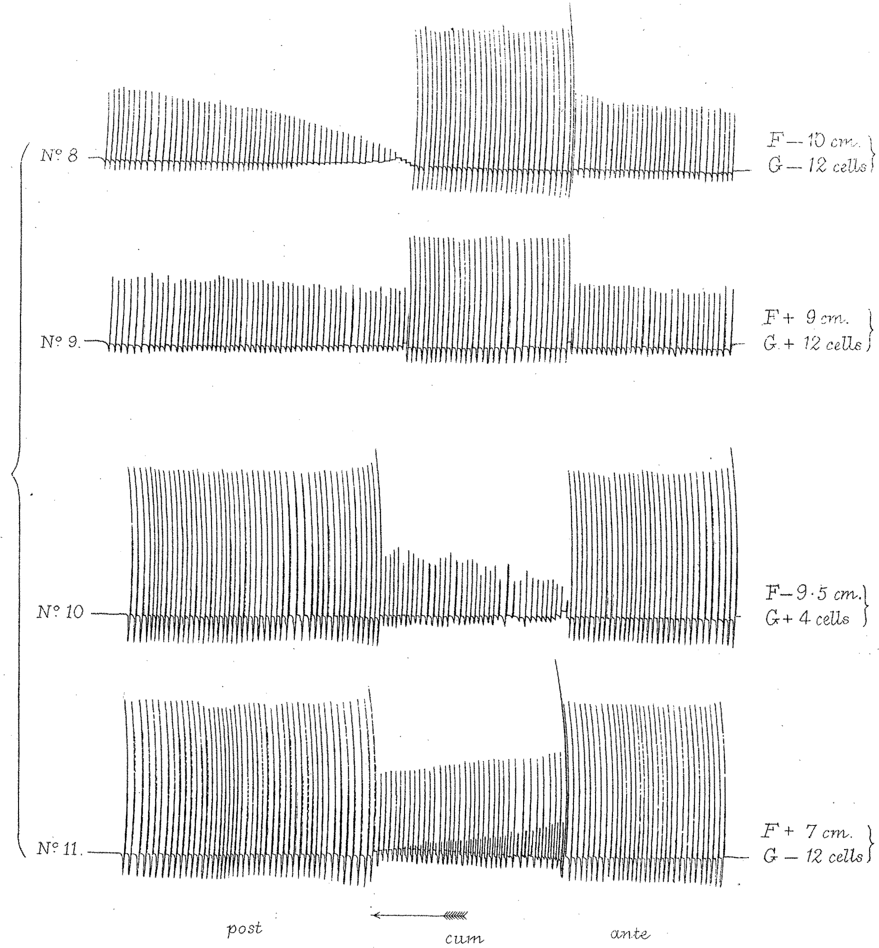
The first four groups of three contractions each are by the anode of the break current with the coil at 9·5, 9, 8·5, 8 centims., at which distances the kathode of the make produced no effect. The last four groups of six contractions each are by the kathode of the make and by the anode of the break at 7·5, 7, 6·5, 6 centims. The first of each pair of contractions is by the make current, the second by the break current. The former (kathodic) gradually overtakes the latter (anodic).

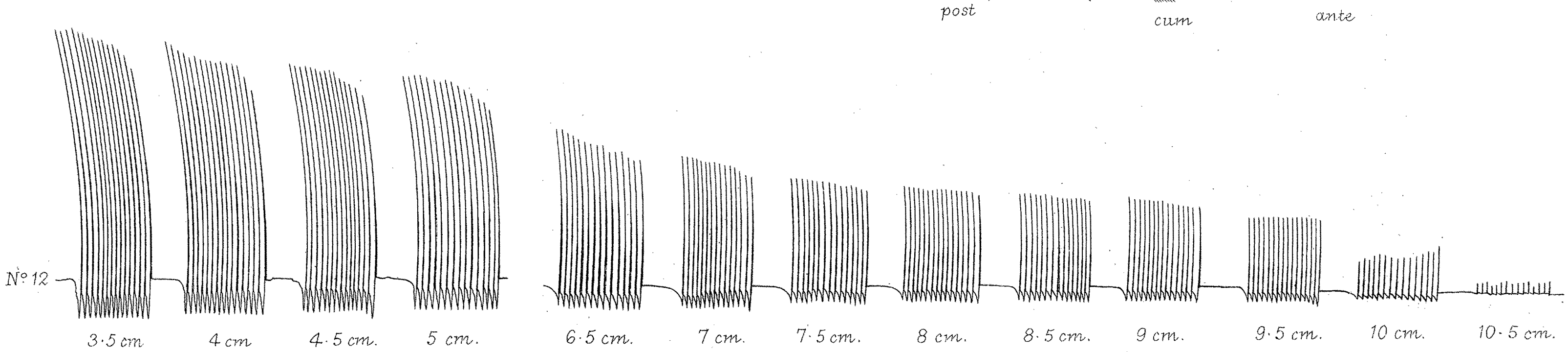
Tracing 34. To show kathodic after-effect. Distance of secondary from primary coil 9·5 centims. No additional resistance in circuit. The first group to the right of the tracing is of induction kathodic contractions before polarisation; the second group is of contractions by the same induction current during the 8th minute of kathodic polarisation by 20 cells (12 m.w.). The following series shows the absence and subsequent rise of contractions after polarisation. The small groups to the left of tracing, marked 1, 2, 3, 4, 5, 6, 7, are of contractions taken at the end of 1, 2, 3, 4, 5, 6, 7 intervals of 15 minutes each, and shows the gradual decline of excitability, the strength of the induction current remaining the same (9·5 centims.) throughout the experiment.

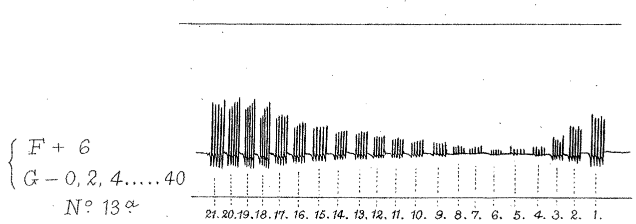
Tracing 35. Series of kathodic closure contractions alternately without and with an uninterrupted galvanic current in the same circuit, 1000 ohms in circuit. Each series last about 1 minute, the duration of current made is about 1 second, that of the interval is about 2 seconds. The strength of current giving the K.C. contractions is the same throughout, viz.: by 10 cells (6 milliwebers). In the three successive series taken during the passage of the uninterrupted current, the strength of the latter is increased, being by 2, 4, and 6 cells in each successive series. The figure shows that the augmentation of K.C.C. is greater with greater strength of the polarising current.

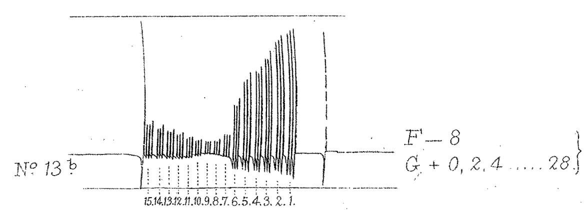
Tracing 36. Series of anodic closure and opening contractions by 30 cells (23 milliwebers) taken on the same plan as the preceding series, with and without an uninterrupted galvanic current in the same direction. It shows augmentation of A.C.C. and diminution of A.O.C. increasing with increasing strength of the polarising current. On comparison with the preceding series it may be recognised that the augmentation of A.C.C. during polarisation is less marked than that of K.C.C.

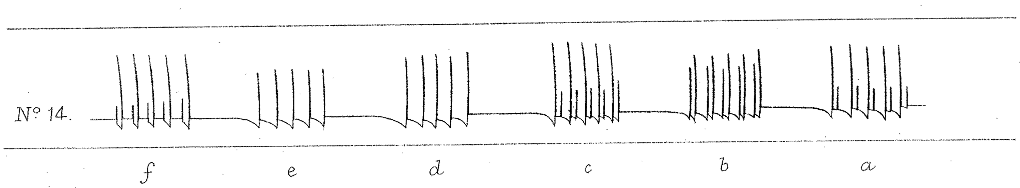

Nº 1.
Nº 2.
Nº 3.
Nº 4.
Nº 5.
Nº 6.
Nº 7.

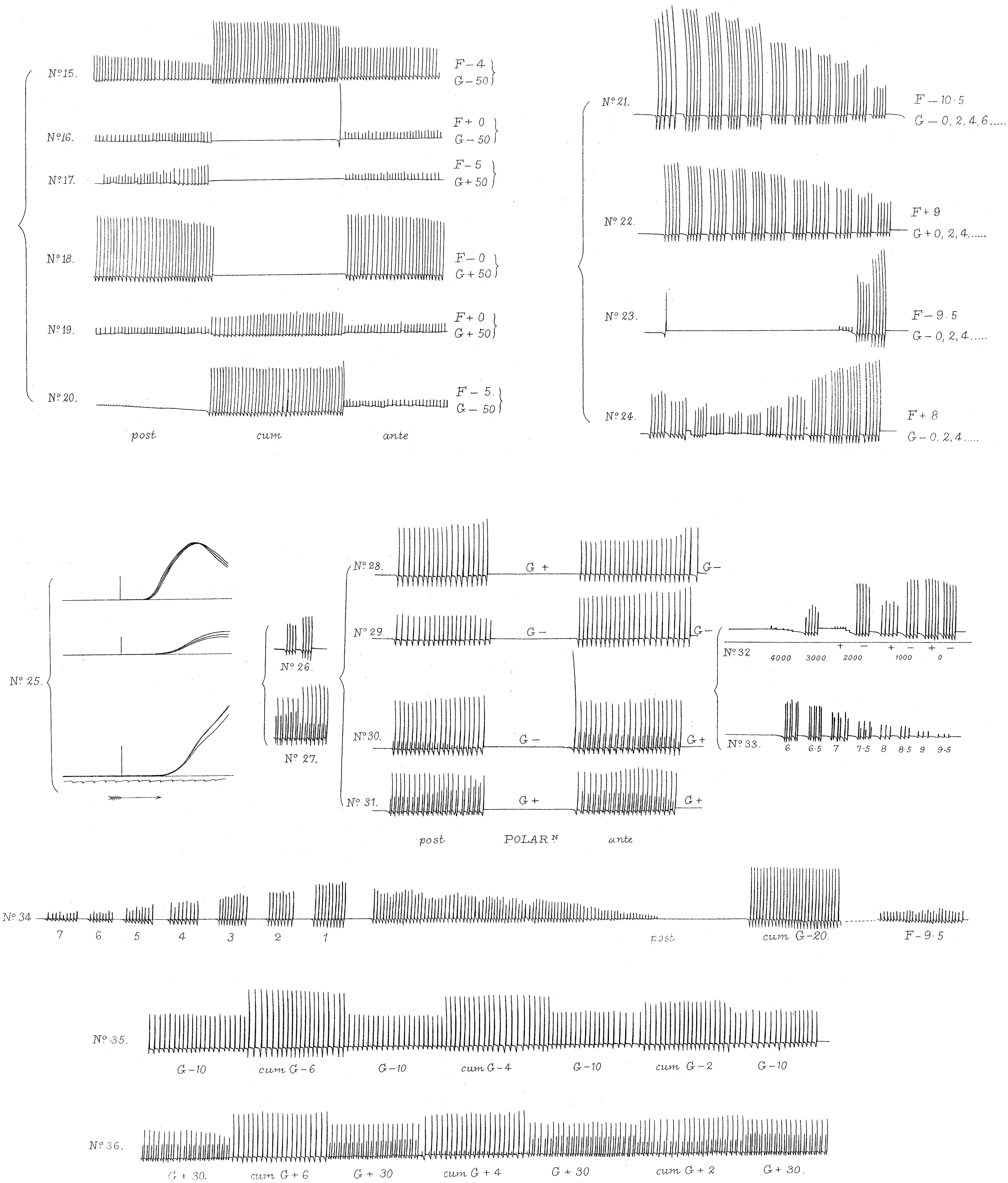

Nº 8
F — 10 cm.
G — 12 cells
Nº 9.
F + 9 cm.
G + 12 cells
Nº 10
F — 9·5 cm.
G + 4 cells
Nº 11.
F + 7 cm.
G — 12 cells
post
cum
ante


Nº 12
3·5 cm
4 cm
4·5 cm.
5 cm.
6·5 cm.
7 cm.
7·5 cm.
8 cm.
8·5 cm.
9 cm.
9·5 cm.
10 cm.
10·5 cm.


F + 6
G — 0, 2, 4..... 40
Nº 13 a
21. 20. 19. 18. 17. 16. 15. 14. 13. 12. 11. 10. 9. 8. 7. 6. 5. 4. 3. 2. 1.


Nº 13 b
F — 8
G + 0, 2, 4 28
15.14.13.12.11.10.9.8.7.6.5.4.3.2.1.


Nº 14.
f
e
d
c
b
a



N° 15.
F – 4
G – 50
N° 16.
F + 0
G – 50
N° 17.
F – 5
G + 50
N° 18.
F – 0
G + 50
N° 19.
F + 0
G + 50
N° 20.
F – 5.
G – 50
post
cum
ante
N° 21.
F – 10·5
G – 0, 2, 4, 6.....
N° 22.
F + 9
G + 0, 2, 4,.....
N° 23.
F – 9·5
G – 0, 2, 4.....
N° 24.
F + 8
G – 0, 2, 4.....
N° 25.
N° 26.
N° 27.
N° 28.
G +
G –
N° 29.
G –
G –
N° 30.
G –
G +
N° 31.
G +
G +
post
POLAR^N
ante
N° 32
4000
3000
+
2000
–
+
1000
–
+
0
–
N° 33.
6
6·5
7
7·5
8
8·5
9
9·5
N° 34
7
6
5
4
3
2
1
post
cum G – 20.
F – 9·5
N° 35.
G – 10
cum G – 6
G – 10
cum G – 4
G – 10
cum G – 2
G – 10
N° 36.
G + 30.
cum G + 6
G + 30
cum G + 4
G + 30
cum G + 2
G + 30.