dimensions of the atoms are concerned in the matter, for the interspace in the centre of a primitive cube of potassium is large enough to house an atom of a gross volume exceeding 17.

In the case of iron the central space is notably smaller than in that of palladium; supposing no expansion to occur on absorption, the largest atom it could contain would have a diameter of 1·392, corresponding to a volume of 2·697.

It is probable, however, that a change in crystalline system is associated with the absorption of gases by iron and nickel. This is suggested by the curious effect produced on the nature of these metals by repeated absorption of hydrogen, at least in the case of nickel, which loses its cohesion and after repeated treatment becomes converted into a friable powder.

The galleries formed by ranges of central spaces present constrictions at intervals corresponding to the places where the four spheres forming the face of a cubelet are most closely approximate; the ratio of the diameter of a sphere that could just traverse one of these constrictions is to that of a sphere which would just occupy a central space as $\sqrt{2} : \sqrt{3}$. Hence the passage of an atom into the central chamber involves either a displacement of the atoms surrounding the entrance or a contraction in the volume of the entering guest. Is it possible that the "singing" of palladium, which accompanies the process of occlusion, is connected with vibratory movements of its atoms as they open and close the entrances to the central chambers?

In conclusion it may be pointed out that all the metals which are known to occlude hydrogen, viz., potassium, sodium, magnesium, iron, nickel, platinum, and palladium, are paramagnetic, sodium and magnesium being the only cases of an uncertain nature, while lead and gold, which offer roomy central spaces for the occupation of hydrogen, but do not absorb it, are diamagnetic.

## "The Electrical Response of Nerve to a Single Stimulus investigated with the Capillary Electrometer. Preliminary Communication." By F. Gotch, M.A., F.R.S., Professor of Physiology, University of Oxford, and G. J. Burch, M.A. (Oxon). Received April 1,—Read May 12, 1898.

The electrical changes which are evoked in nerve by a single stimulus have up to the present been but little investigated. The examination of the phenomena has been almost entirely limited to observations upon the galvanometric deflections caused by the summed effects of a rapid succession of excitations, and rheotome methods,

carried out along these lines by Bernstein, Hermann and others, have yielded results of great value. It is, however, only on the assumption that the aggregate value of the successive electromotive states gives at any moment a faithful representation of each component member of the series, that deductions can be drawn from such rheotome observations as to the characters of the single electrical response. Attempts have been made to obtain indications of the response to a single stimulus by other methods, but without very satisfactory results. As far as we know, the only permanent record of such a response is that obtained by Gotch and Horsley in 1888 with the assistance of Burch; the record was that of the photographed excursion of a sensitive capillary electrometer.*

For some time the authors have been engaged in endeavouring to obtain with the capillary electrometer records of the single response of nerve which should be large enough not merely to indicate its occurrence but to afford data for determining its chief characteristics.

This object has been so far attained that they are now able to measure the electromotive changes of nerve in response to a single stimulus, by the application to the photographic records of the process of analysis introduced by one of them.† (G. J. B.)

The electrometer employed, made especially for the purpose by Burch, is more sensitive and, at the same time, more rapid in its action than any they have hitherto used. The latter quality, while essential to success, entails great liability to disturbance by mechanical vibrations, and considerable difficulty was met with on this account. The following form of support was ultimately adopted. A brick pillar was built up to the level of the ground upon a concrete foundation at the bottom of a pit 7 feet deep. On the pillar was placed a stout box containing some 5 cwt. of clay and upon the box three cast-iron plates, each weighing 1 cwt. Each plate was separated from the one below by three bags of sawdust, the bags forming supports, so arranged in opposite triangles as to come alternately under the nodes and loops of the plates. The electrometer, with its accompanying microscope, was fixed to the topmost plate, and was thus efficiently isolated from the rest of the apparatus and from the floor of the working room.

The excursions of the meniscus were recorded by a pendulum motor,‡ the image being projected by a Leitz 3 mm. objective upon the sensitized plate. This was carried by the motor across the optic axis in a circular arc at a distance of 125 cm. from the lens, giving

* 'Roy. Soc. Proc.,' vol. 45.

† 'Phil. Trans.,' A, vol. 183 (1892), pp. 81—105.

‡ See "The Capillary Electrometer in Theory and Practice," G. J. Burch; also Burdon Sanderson, 'Journ. Phys.,' vol. 18, pp. 126—134.

a magnification of 416 diameters. The velocity of the transit of the plates in the experiments now described varied between 14 and 70 cm. per second; it was determined in every instance by recording upon the plate the vibrations of a tuning fork having a period of 500 per second.

The sciatic nerves of large specimens of *R. temporaria* were used in all the experiments, and the present results were obtained during the winter months, *i.e.*, from October to March.

The prepared nerve was placed in a moist chamber kept at from 4° to 6° C.; the chamber contained non-polarisable electrodes for the electrometer and polarising connections, and a pair of exciting electrodes. In every case the nerve was excited by a single stimulus applied to the sciatic plexus 20 to 30 mm. from the nearest of the electrometer contacts.

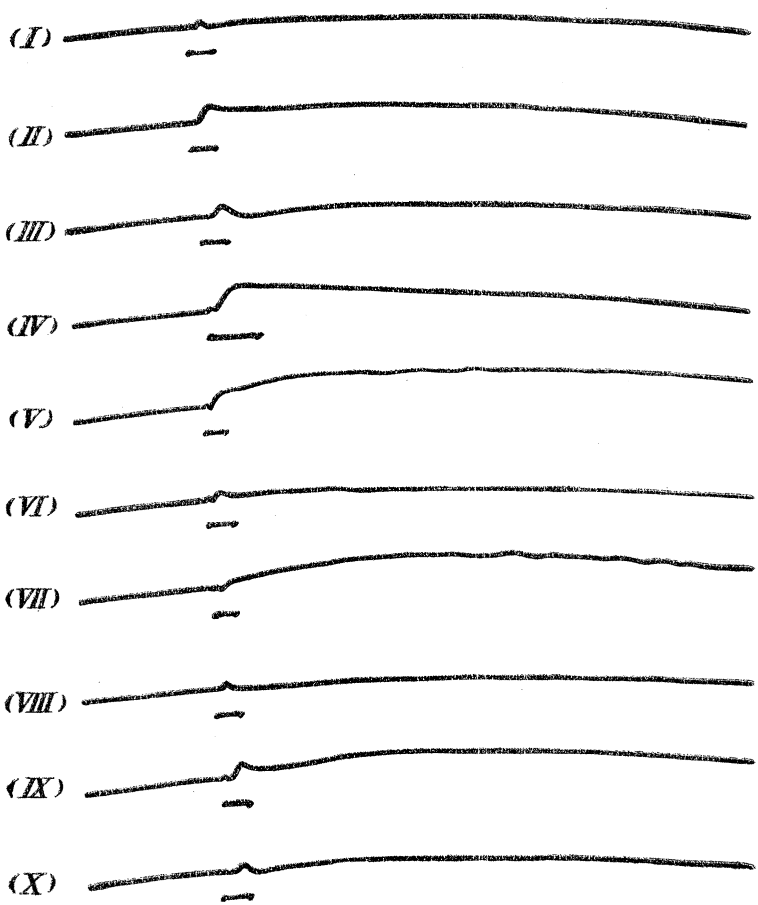
The form of stimulus usually employed was a relatively feeble induced current caused by the opening of the primary circuit of a standardised induction coil, which included one Daniell cell; the opening was effected by the pendulum motor and the primary coil contained no core. Each single stimulus of this type produces a movement of the meniscus when the electrometer contacts are suitably arranged upon the nerve. The movement is in some cases perceptible to the eye when the highly magnified image is projected upon a screen, but in many instances is only visible after the development of the photographic record. That the movement was not due to an escape from the exciting circuit is shown as follows:—The direction and character of the movement is unchanged whatever the direction of the exciting current; the escape, if present at all, is clearly indicated in the record as a rapid displacement of the meniscus, preceding by a distinct interval the larger movement which is here referred to; such antecedent escape excursions remain unmodified in character under conditions which materially affect both the larger movement and the physiological condition of the nerve (polarisation, $CO_2$, &c.); the escape, if present, is increased by augmenting the intensity of the exciting induced current, whilst the larger change reaches a maximum with a certain intensity of stimulus; finally, the larger movement is obtained by mechanical excitation such as the single tap of a light hammer arranged after the method of v. Uexküll.*

In order to facilitate the description of the excursions obtained, selected photographs have been projected upon a screen and the outlines of the variation in the level of the meniscus carefully traced; a number of different curves are thus brought into juxta-position. A reduced copy of this is given in fig. 1. Some of the actual records will, it is hoped, be produced in a more extended communication, but the curves given in the figure are not merely faithful reproduc-

* v. Uexküll, 'Zeits. f. Biol.,' vols. 31, 32, 1895.

tions of the originals, but correspond as regards dimensions with the records upon the photographic plates. The curves are to be read from left to right; the short line under each indicates 1/100 of a second. In several instances, such as curves (i), (iv), (v), (vi), (vii), and (ix), the escape of the exciting current, arranged to be in the same direction as the change due to the response, is seen preceding this. When present it indicates the moment of excitation. In the actual records this moment was marked on each plate by photographing the movement of the opening key which caused the exciting break induction shock.

Fig. 1.



*Freshly Prepared Nerve; both Electrometer Contacts upon the Uninjured Surface.*

The nerve in these preparations was dissected out from the spinal column to the knee, and the muscles below the knee were left attached to the preparation. With the electrometer contacts arranged at distances of 5 and 15 mm. respectively from the knee end, no resting difference of potential was perceptible. A single electrical or mechanical excitation of the sciatic plexus 45 mm. from the knee end of the nerve causes no visible displacement in the level of the mercurial meniscus, but the photographic record shows a rapid excursion indicating that the contact nearest the seat of excitation (proximal) is first negative and then positive to that more remote (distal). The character of the rapid up and down movement is indicated in curve (i) fig. 1. If the contacts are placed further apart (25 to 30 mm.) the spike present in the record is more pronounced, the ascending and descending limbs being further apart.

*Freshly Prepared Nerve; the Proximal Electrometer Contact upon the Uninjured Surface, the Distal upon a recently made Cross Section at the Knee End.*

The contacts were arranged 10 mm. apart, and the well-known resting difference of potential existed between them. This demarcation difference caused a downward movement of the level of the meniscus amounting in some cases to 10 cm. upon the screen. It was not compensated by the use of any external E.M.F., but the pressure was altered so as to bring the meniscus up again to its proper position. During the presence of this permanent demarcation effect each single excitation of the plexus, whether electrical or mechanical, is followed by a visible displacement in the level of the image. The photographic record, see fig. 1 (ii), shows a rapid upward movement, followed by a prolonged tail in place of the downward movement obtained with uninjured nerve, thus indicating a more persistent change of the same sign as the initial one; this disappears comparatively slowly, and is of much lower E.M.F. than that which produces the initial rise.

*Excised Nerve kept in the Cold from 24 to 90 hours in 0·6 per cent.* NaCl *made with Tap-water containing Traces of Calcium Salts.*

That nerves kept in this way retain their excitability is shown by the fact that if the muscles are not detached they respond to excitation of the nerve trunks.

On connecting such an excised nerve with the electrometer, no

marked difference of potential is found to exist between the cross-section and any point on the surface.

A single excitation of the plexus rarely produces a displacement of the image of the meniscus which is visible to the eye, but in the photographic record such displacement is indicated by a definite excursion of the character shown in fig. 1 (iii). The form is a spike, the limbs of which are more widely separated than those of the uninjured fresh nerve fig. 1 (i). It indicates that the proximal electrometer contact becomes first negative and then positive to the distal one, but as the period at which the change of sign occurs is later than in the fresh nerve the rate of transmission of the excitatory process, of which the electrical change is an index, must be slower in the kept than in the fresh nerve.

If a new cross-section is made at the knee end and the distal contact placed upon it, the resting demarcation change is at once produced causing a marked downward displacement of the meniscus. Each single excitation of the plexus now causes a change plainly visible to the eye and the record shows as in fig. 1 (iv) that there is an excursion of considerable size, the initial rise being followed by the prolonged tail, which is seen in the freshly injured nerve.

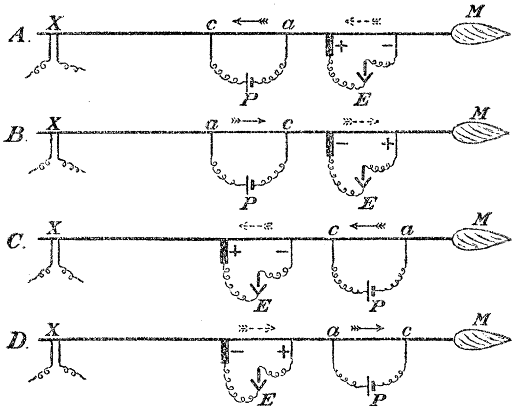
### *The Alterations produced by the passage of a Polarising Current.*

It is well known that the passage of a galvanic current through a portion of nerve profoundly modifies its electromotive conditions. During the passage the regions outside the part traversed by the polarising current are the seat of changes such that currents of similar direction to the polarising one are present in the extrapolar regions.

It has been shown by Bernstein, Hermann and others that the excitatory effects are modified under these conditions, and a considerable part of the present investigation has been devoted to the determination of the character of the change evoked by a single stimulus under these circumstances.

The experiments were arranged along the lines shown in fig. 2. The excitation was restricted as before to the sciatic plexus, but an additional pair of non-polarisable contacts was connected with a circuit comprising a rheochord and two Daniell cells. These polarising contacts were placed either between the exciting and the electrometer ones as in arrangements A and B of fig. 2, or on the distal side of the electrometer ones as in arrangements C and D. In each case the polarising current may be reversed in direction and four different modifications can be thus studied. It will be observed that there is a fundamental difference as regards the position of the electrometer contacts, and this is accompanied by corresponding

FIG. 2.




X indicates the seat of excitation on the sciatic plexus; M the muscles below the knee; P indicates the circuit traversed by the polarising current; E the electrometer circuit. The unbroken arrow indicates the direction of the persistent polarising current in the nerve, the dotted one that of the persistent extrapolar effect thus produced. The anode and cathode of the polarising current are indicated by the letters *a* and *c* respectively. The signs (+) and (−) refer to the persistent difference of the electrometer contacts during polarisation.

differences in their electrical state. The proximal electrometer contact is that nearest the seat of excitation, and is represented in the figure by the broad dark line. In arrangement A it lies in the anodic extrapolar region, and owing to polarisation effects, is rendered positive to the distal one during the polarising flow; in B it is in the cathodic extrapolar region, and is negative to the distal one during such flow; in C it is in the cathodic region, but, as in A, is positive to the distal one, whilst in D it is in the anodic region, but is negative to the distal one as in the case of B.

The results as regards the character of the excitatory change differ in accordance with the particular arrangement employed, but it will be seen that with arrangements A and C, the records of the response to a single stimulus resemble one another inasmuch as the prolonged tail, previously referred to as characteristic of the nerve with a fresh cross-section, now becomes strikingly evident. On the other hand with B and D the records resemble that of the uninjured nerve, the spike alone being present.

It will be convenient to describe the results under two headings in accordance with this general subdivision; and, as experiments have been made on the preparations of all the types previously referred to, the results under each heading comprise those observed in fresh nerves uninjured and with cross-section, and in kept nerves.

*Nerve during passage of a Polarising Current of such direction that the Proximal Electrometer Contact is positive to the Distal One.*

(*a*) Fresh nerve prepared with electrometer contacts on surface and cross-section. The proximal contact is in this case positive to the distal owing to the resting difference ; this is increased by the anodic extrapolar effect of a polarising current as in arrangement A (fig. 2). Each single stimulus of the plexus causes a very marked displacement of the meniscus plainly visible to the eye. The photographic record is of the character shown in fig. 1 (v). The initial rise is succeeded by a pronounced and prolonged effect of similar sign : it indicates that the prolonged change present in the unpolarised nerve and figured in fig. 1 (ii) is increased.

(*b*) Fresh nerve uninjured with both electrometer contacts upon the surface. There is no difference of potential between the contacts, but during polarisation the anodic extrapolar effect in arrangement A and the cathodic extrapolar effect in arrangement C are such that the proximal electrometer contact is positive to the distal. This is particularly the case with arrangement A owing to the nearer proximity of the contact to the polarised region.

The persistent extrapolar state is indicated by a downward movement of the meniscus which reaches a certain level and is raised by suitable alteration of pressure to the middle of the optical field. Each single stimulus applied to the plexus, although in the unpolarised nerve not followed by any displacement visible to the eye, produces now a visible change. The records show that the initial rise is still present, but that it is succeeded by a prolonged effect of similar character to that obtained in fresh nerve with the distal contact upon the cross-section. The curve given in fig. 1 (vii) shows its form.

(*c*) Nerve kept in 0·6 per cent. NaCl. It has been already stated that after twenty-four hours, the excised nerve gives no difference of potential when the electrometer contacts are placed upon cross-section and surface.

Polarisation may be produced of such character that the proximal electrometer contact (*i.e.*, that nearest the seat of excitation) is positive to the distal one, by arrangement A or C, as in the case of uninjured nerve. The effect caused by the single stimulus of the plexus is modified in the same way as in the previous class of observations. Instead of the spike which characterises the unpolarised nerve, the records show that the initial rise is followed by a prolonged effect of the form shown in fig. 1 (ix). As in the case of the uninjured nerve, this is more pronounced when the arrangement is that given in A than that of C (fig. 2) for the reason previously referred to.

If the kept nerve is subjected to a fresh cross-section, then the results of polarisation of this character resemble those described under (*a*) as occurring in the fresh nerve with a cross-section.

*Nerve during passage of a Polarising Current of such direction that the Proximal Electrometer Contact is negative to the Distal One.*

(*a*) Fresh nerve with electrometer contacts upon surface and cross-section. The arrangement made use of is that given in fig. 2, B, and the resting demarcation difference is now largely diminished or entirely overpowered by the polarisation extrapolar effect in the cathodic region. The single excitation of the plexus rarely produces any visible movement of the meniscus, and the record upon the plate is found to be of the character indicated in fig. 1 (vi). It is evident that this differs from both the unpolarised nerve, fig. 1 (ii), and the nerve in the state of opposite polarisation, fig. 1 (v), by the circumstance that the early part of the effect now takes the form of a small spike, and that the terminal prolonged portion forming the tail is reduced to very small proportions. The curve thus indicates that the proximal contact becomes first negative and then positive in rapid succession, whilst the prolonged effect no longer masks the second positive change as in the other instances just referred to.

(*b*) Fresh nerve uninjured, with contacts both upon the surface. Polarisation effects resulting in relative negativity of the contact proximal to the seat of excitation may be attained by either an arrangement like that given in fig. 2 B, or one like that of D. In the first case the electrometer contacts are in the cathodic extrapolar region; in the second case they lie in the anodic extrapolar region.

With either arrangement a single stimulus applied to the plexus produces no alteration in the level of the meniscus visible to the eye, but each plate when developed shows a record of the type indicated in fig. 1 (viii); the form of the photographed excursion is that of a very small spike the two limbs of which follow each other in rapid succession. The spike is sometimes, especially with arrangement D, followed by a curved prolongation dipping for a short distance below the resting level, but in no case has an effect in this direction been obtained at all comparable with that already referred to as producing the negative tail during the oppositely directed polarisation.

(*c*) Nerve kept in 0·6 per cent. NaCl. Polarisation producing relative negativity of the electrometer contact proximal to the seat of excitation can be attained by either of the two arrangements, B or D (fig. 2). When present, a single excitation causes no visible displacement of the meniscus, but the photographic records show that there is an abrupt up-and-down excursion of the type indicated in fig. 1 (x). When compared with that produced in the unpolarised nerve, fig. 1 (iii), the form of the spike is seen to be one in which the ascending and descending limbs are more closely approximated, and a slight dip below the resting level follows the completion of the excursion.

From the foregoing description it will be evident that when the proximal electrometer contact is relatively positive to the distal one, whether owing to the extrapolar changes due to the passage of a polarising current, or to the presence, in the case of a recent cross-section, of the resting demarcation difference, the electrical response evoked by a single stimulus has certain definite characteristics; the most conspicuous of these are the increased magnitude of the initial movement forming the ascending limb of the spike and the presence of a more prolonged change of similar sign to this. On the other hand when the contact proximal to the seat of the stimulus is relatively negative to the distal one and this latter therefore relatively positive, other characteristics of the response are accentuated; the initial movement forming the ascending limb of the spike is quickly checked and succeeded by one of opposite character, whilst the prolonged change disappears.

It would be beyond the scope of the present communication to enter upon any discussion as to the physiological meaning of the changes here referred to. It may, however, be pointed out that the results fully support the conclusions arrived at by Hermann from rheotome observations, viz., that those portions of the extrapolar region nearer the anode are during polarisation capable of a more pronounced excitatory electrical change than those more remote, whilst those portions of the cathodic region nearer the cathode are susceptible of a less pronounced change than those more remote.* New features are, however, brought to light by the present research as indicated in the preceding paragraphs.

### *The Electromotive Force of the Changes.*

The records allow of the calculation of the E.M.F. of the potential difference between the contacts. The table appended to this communication gives five examples of the results of the method of analysis introduced by one of us† (G. J. B.) The five examples selected are the analyses of excursions such as are figured in curves (i), (ii), (iii), (vii), and (viii) of fig. 1. In addition to the intrinsic interest which attaches to the estimation of the E.M.F. of the electrical response to a single stimulus, the analyses present certain features which may be briefly alluded to.

The maximum E.M.F. it will be observed may reach as much as 0·032 volt (Table IV), a suggestive fact in relation to the view held by us as to the nervous origin of the E.M.F. of the response in the electrical organ of fishes.‡ This maximum is attained very rapidly

* See Hermann, 'Handbuch der Physiologie,' vol. 2 (i), p. 167.

† Burch, 'Phil. Trans.,' A, vol. 183 (1892), pp. 81—105.

‡ Gotch and Burch, 'Phil. Trans.,' B, vol. 187 (1896), p. 382.

### Analysis of Five Records of Single Response.

The difference of potential between the proximal and distal contacts is given in terms of relative negativity (−) or positivity (+) of proximal as compared with distal contact. (Distance between contacts = 10 mm.) The differences of potential are given in decimals of a volt.

| Time after excitation of nerve 30 mm. from proximal contact. | I. Uninjured nerve. Electrometer contacts 10 mm. apart and both on uninjured surfaces. | II. Fresh nerve with cross-section. Proximal contact on uninjured surface + to distal on cross-section. | III. Nerve excised and kept 24 hours in 0·6 per cent. NaCl. Proximal contact on surface, distal on end. | IV. Fresh uninjured nerve. Polarisation such that proximal contact is persistently + to distal one. | V. Fresh uninjured nerve. Polarisation such that proximal contact is persistently − to distal one. |
|---|---|---|---|---|---|
| sec. | | | | | |
| 0·0020 | start | start | nil | nil | nil |
| 0·0025 | −0·0218 | −0·0262 | ,, | ,, | start |
| 0·0030 | −0·0218 | −0·0176 | ,, | ,, | −0·0056 |
| 0·0035 | −0·0218 | −0·0144 | ,, | start | −0·0081 |
| 0·0040 | −0·0002 | −0·0127 | ,, | −0·0083 | −0·0115 |
| 0·0045 | +0·0145 | −0·0103 | start | −0·0135 | −0·0162 |
| 0·0050 | +0·0128 | −0·0081 | −0·0093 | −0·0182 | −0·0220 |
| 0·0055 | +0·0113 | −0·0054 | −0·0145 | −0·0250 | −0·0115 |
| 0·0060 | +0·0101 | −0·0029 | −0·0178 | −0·0329 | −0·0001 |
| 0·0065 | +0·0099 | −0·0004 | −0·0093 | −0·0328 | +0·0051 |
| 0·007 | +0·0054 | +0·0015 | −0·0002 | −0·0328 | +0·0099 |
| 0·008 | +0·0007 | +0·0016 | +0·0041 | −0·0003 | +0·0084 |
| 0·009 | +0·0004 | +0·0020 | +0·0050 | +0·0002 | +0·0070 |
| 0·010 | +0·0000 | +0·0023 | +0·0113 | 0·0000 | +0·0058 |
| 0·011 | .. | +0·0023 | +0·0116 | 0·0000 | +0·0037 |
| 0·012 | .. | +0·0023 | +0·0024 | −0·0001 | +0·0019 |
| 0·013 | .. | +0·0026 | +0·0011 | −0·0002 | 0·0000 |
| 0·014 | .. | +0·0029 | +0·0010 | −0·0005 | |
| 0·016 | .. | −0·0002 | +0·0007 | −0·0011 | |
| 0·018 | .. | −0·0019 | +0·0003 | −0·0016 | |
| 0·020 | .. | −0·0023 | 0·0000 | −0·0022 | |
| 0·030 | .. | −0·0019 | .. | −0·0016 | |
| 0·040 | .. | −0·0013 | .. | −0·0010 | |
| 0·050 | .. | −0·0006 | .. | 0·0000 | |
| 0·060 | .. | 0·0000 | | | |

especially in the fresh nerve; the first indications of its presence in fresh nerve at 6° C. occur 0·002 second after the stimulation of the plexus when the seat of this stimulation is 30 mm. from the proximal electrometer contact. The response is thus propagated from the seat of stimulation at a rate of from 10 to 15 metres per second under these conditions. This is confirmed by the time relations of the culmination and commencing decline in the change, for in fresh nerve this begins in about 0·001 second with a distance of 10 mm. between the proximal and distal contacts. In the example of kept

nerve given in the third column, both the commencement and the culmination of the initial change are retarded, the propagation rate in this nerve at a temperature of 6° C. being slowed to 6 metres per second. A comparison of the fourth and fifth columns shows the retardation in the anodic as compared with the acceleration in the cathodic extrapolar region. Finally the time relations and the relative E.M.F. of the prolonged effect present in the instances given in the second and fourth columns may be compared with those of the initial change present in all the examples. It will be seen that the change producing the prolonged tail of the photographic record is one which differs from that producing the initial spike in the following important particulars: it develops slowly, taking from 0·006 to 0·01 second to culminate, its maximum E.M.F. is only one-tenth of that of the initial change, and it subsides slowly. It is not present in the instances given in columns I, III, and V.

In a more extended communication the authors hope to bring forward other features of the response of nerve, particularly the characters exhibited by the records of the changes produced by a series of stimuli and of those produced during reflex discharge of the central nervous system.

## "On the Magnetic Susceptibility of Liquid Oxygen." By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and James Dewar, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, London, &c. Received May 9,—Read May 12, 1898.

In a previous communication* we have described the initial investigations made by us to determine directly the numerical value of the magnetic permeability of liquid oxygen, and we there indicated that we hoped before long to present to the Royal Society the results of other experiments made by a different physical method which we anticipated would enable us to state whether liquid oxygen has a constant magnetic susceptibility, or whether, like a ferromagnetic substance, its magnetic susceptibility alters when subjected to different magnetic forces.

We have recently obtained results which, though limited to a certain range of force, we think afford fairly trustworthy values of the magnetic susceptibility of liquid oxygen under magnetising forces varying from 500 to 2500 C.G.S. units, and place them therefore on record.

* 'Roy. Soc. Proc.,' 1896, vol. 60, p. 283, "On the Magnetic Permeability of Liquid Oxygen and Liquid Air."