"The Demarcation Current of Mammalian Nerve. (Preliminary Communication.) I. The Demarcation Current of Mammalian Nerve." By J. S. MACDONALD, B.A., L.R.C.P.E., University College, Liverpool, Research Scholar of the British Medical Association. Communicated by Professor SHERRINGTON, F.R.S. Received July 28, 1900.

1. A necessary preliminary to the study of the distribution of the demarcation current and source is an examination of the character of the resistance of the particular nerves in which phenomena are observed.

The resistance per cm. of the nerves examined—vagus, phrenic, and sciatic nerves of dog and cat, &c., varies with the nerve and with the animal

Vagus	....	Horse, 2000	ohms per cm.
,,	....	Dog, 12,500	,, ,,
,,	....	Cat, 31,000	,, ,,
Sciatic	....	Dog, 3500	,, ,,
,,	....	Cat, 4500	,, ,,

the variations depending upon the character of the nerve and presumably of the individual fibres, upon its sectional area, and probably upon intrinsic differences between the average salt content of the tissues of different animals.

But taking any individual nerve the estimated value of the resistance per cm. varies with the length of the piece, from the determination of the resistance of which the estimation is made.

Thus keeping one electrode at a fixed point of a nerve, the cross-section A, moving a second electrode from point to point, B, C, D, &c., and measuring the resistance included between A and these several other points, a series of determinations of the resistance of various lengths of the same nerve are made. From a knowledge of the length of the piece and from this determination, an estimation of the resistance per cm. of the nerve is obtained which is greater with each diminution of length.

Experiment.—Vagus Nerve of Dog.

Piece.	Length.	Resistance.	Resistance per cm.
AB	15 mm.	29,500 ohms.	19,700 ohms.
AC	30 ,,	58,500 ,,	19,500 ,,
AD	50 ,,	85,000 ,,	17,000 ,,
AE	65 ,,	108,000 ,,	16,600 ,,
AF	83 ,,	133,500 ,,	16,080 ,,

The calculated resistance per cm. is also considerably greater when the resistance is measured from one point on the longitudinal surface to another than in the case in which the resistance of a similar length is taken from the cross section to a point on the longitudinal surface, and greater still than the resistance of a similar length bounded by two cross sections.

When therefore a knowledge of the resistance is required as a basis for calculations, a direct determination of the resistance is only of value when the resistance is required to a current having the same path as that used for the measurement of resistance.

In any other case, as when the fraction of the longitudinal resistance corresponding to a fraction of the length of the nerve is required, it is better to use a calculated value than the value of the directly determined resistance. This calculated value is best obtained from the resistance per cm. of the longest available stretch of the nerve.

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2. If a point on the longitudinal surface is connected to the cross section through a pair of non-polarisable electrodes and an outer wire path, and a current is found to traverse the circuit so formed, then the current can not only be found in the outer wire path by means of a galvanometer placed in it; but can also be followed in a return direction in the nerve, travelling in the opposite direction from the cross-section to the longitudinal surface, by means of the new differences of potential, which the formation of the outer circuit immediately establishes in every intervening point of the nerve.

This is true when any arbitrarily selected point on the longitudinal surface is connected to the cross section. In each case the return current through the nerve is found established as a new phenomenon, due to the closure of the outer path, and is exactly the current due to the action of a source of E.M.F. of the value determined as the potential difference between the point on the longitudinal surface and the cross section in a circuit of the resistance found.

Experiment.—Vagus Nerve of Cat.

The nerve was excised and laid upon four non-polarisable electrodes, A, B, C, D. The cross section was at A, the nerve stretched a small distance beyond electrode D, and was suspended to the wall of the moist chamber by a silk thread.

The potential difference (so called) between points A and D was determined as 0·00712 volt.

The potential difference between the two intermediate points B and C was zero, the points being equipotential.

Points A and D were now permanently connected through the

resistance of a pair of non-polarisable electrodes and a wire joining them, forming in all a circuit of resistance 135,000 ohms.

Nerve AD	= 128,000 ohms.
Electrodes	= 7000 ohms.
The length of nerve AD	= 4·3 cm.
" " piece BC	= 1·8 cm.

The "calculated value" of resistance B, C = 54,000 ohms.

The value directly determined = 63,000 ohms.

After closure of circuit A, D, the intermediate point B, nearest to the cross section, became "+" to the more distant intermediate point C, which was "−".

The value of this difference was 0·0028 volt.

If in this experiment it is assumed that, (1) the only source of E.M.F. is that found and measured as the potential difference between A and D, 0·00712 volt: and (2) that the path of the current is the simple one of nerve electrodes and wire, *i.e.*, the path through the nerve is simple, and not divided into two sets of resistances carrying a current in opposite directions (circuit completed in nerve itself): then a difference of potential should be found between points B and C of this path

$$= \frac{r}{R} E,$$

$$= \frac{54,000}{135,000} 0{\cdot}00712 \text{ volt},$$

$$= 0{\cdot}00284 \text{ volt},$$

and this is practically the value actually found.

In many similar experiments which have been performed, this agreement of value found and value calculated has been found to hold good within a small limit of error, entirely owing to an alteration of the E.M.F. due to the cross section and to the lapse of time taken to perform the experiment.

When there is a pre-existing difference of potential between the points B and C, this difference subtracts from the newly-acquired value due to the closure of the circuit A, D, and the value actually found is the algebraical sum of the pre-existing and the newly-acquired difference.

Since a pre-existing difference between B and C is the source of the "longitudinal current," the last point in the above statement is considered of importance, as tending to show that the source of the demarcation current and that of the longitudinal current can be so separable as to oppose one another in a conveniently arranged circuit.

3. Similar experiments show that the closure of a circuit for the observation of a *longitudinal current* also gives rise to similar changes of potential in the intervening stretch of nerve.

Similar experiments show that the closure of a circuit for the observation of *an electrotonic current* affects the potential of every intervening point in the same way.

So that if a path joining two points on a nerve is found to be carrying a current, whether it be demarcation, longitudinal, or electrotonic, this current can be traced in the longitudinal axis of the nerve, making use of its gross longitudinal resistance, and not interfered with by currents from any other of the possible sources of E.M.F., discovered by the determination of pre-existing differences of potential of intervening points. None of these sources are brought into action so as to affect a current in the longitudinal axis of the nerve until an additional outer circuit of non-polarisable electrodes and wire is formed for them; they then at once are brought into action and add to or subtract from the original.

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4. Long stretches of mammalian nerve—vagus, sciatic, and phrenic—of about 10 cm. long have been taken, and laid upon an ebonite scale. The E.M.F.s available between either cross section, and the points distant 1, 2, 3, 4, &c. cm. *from one end*, have been systematically measured, and from the measurements curves obtained with the nerve as abscissa and the ordinates the E.M.F. between the immediately underlying point of longitudinal surface of the nerve and the cross section.

Whatever be the difference between the E.M.F.s due to the two cross sections (in some cases a difference of height of maxima o 0·006 volt, the lower one, *e.g.*, being 0·002 volt, the higher 0·008 volt), and whatever be the peculiarities of the curves, they are, notwithstanding the difference of level, parallel for the greater portion of their extent. The curve due to the available force between one cross section and the longitudinal surface repeats all the maxima and minima of the curve due to the other cross section at a different level, the relations between the maxima and minima being preserved unaltered.

Such a condition of affairs is most readily explained by the assumption that the determination of E.M.F. between a point on the longitudinal surface and the cross section is always the determination of the algebraical sum of two opposing forces, one acting radially at the point on the longitudinal surface, and one at the cross section acting in the longitudinal axis of the nerve; and that the radial force remains the same at a point of the longitudinal surface, whereas there may be and usually is a difference between the two longitudinal forces, one at each cross section.

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5. Selecting one cross section and systematically measuring the E.M.F. available between this and points on the longitudinal surface, drawing a complete curve (force diagram) at regular intervals of 30′ between each curve, the levels of the curves fall with diminishing rapidity, and a gradual change occurs in the form of each curve.

After the nerve has been removed some hours from the animal, the maximum E.M.F., the highest point of the curve, may have sunk to one-tenth of its original value. If now the nerve is taken and placed for a short period (five minutes) in tap water, a maximum E.M.F. is obtained considerably greater than the maximum obtained from any point of the same nerve when freshly removed from the recently-killed animal. If the value of the demarcation source is taken as an index of the condition of the nerve, then a rejuvenation has taken place with the immersion in tap water.

This increased value remains for some time, the curve being of not much different form, and the rate of fall of level being similar to the rate of fall from the original maximum. If the nerve be left in tap water for twenty-four hours, a demarcation current, a difference of potential between each point on the longitudinal surface and the cross section is observed, giving a curve very similar to that obtained after the first immersion in tap water twenty-four hours previously.

If one waits after the death of an animal until *rigor mortis* is completely established, and a nerve be then removed, only a small trace of demarcation current is obtainable from it, and the curve of E.M.F. due to a cross section is at an extremely low level. If now this nerve is left for a short period (five minutes) in tap water, a maximum E.M.F. is obtainable from it higher than that obtained from the fresh nerve of the recently-killed animal, and as high as that obtained after the immersion of the fresh nerve in tap water, and there is no marked difference in the form of curve (force diagram).

If a nerve is removed at once after the death of an animal, and the E.M.F. between a "maximal" point and the cross section is taken (1) immediately (2) after a short immersion in 0·9 per cent. saline, then it is seen that the 0·9 per cent. (normal) saline has diminished the E.M.F. If the nerve be now immersed in 0·45 per cent. saline the original value is returned, and is increased by a further immersion in 0·3 per cent., 0·2 per cent., 0·1 per cent. saline solution, each further dilution increasing the E.M.F. A return of the nerve through the series diminishes in each case the E.M.F., to be renewed by a subsequent return to the weaker solution.

The maximum effect is obtained by the action of tap water, and a very considerable reduction of this maximum is obtained by a subsequent immersion in 0·1 per cent. saline, to be followed by a return to the maximum with a return to the tap water.

There is no sign of any critical point marking the separation of two possible

phenomena, one a function of the condition of life of the nerve and the other a physical phenomenon dominated by the salt content of the nerve, and capable of continuation long after its death.

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6. If a number of threads are twisted together to form a rope and the rope laid upon two non-polarisable electrodes of the usual type, no current is found between the electrodes if the thread rope is previously uniformly wetted with a saline solution or with tap water. If on such an uniformly wetted rope a drop of saline solution of a different concentration is placed at a point closer to one electrode than another a current is found in the circuit, and a source of E.M.F. quite comparable in value to the maximal value of the demarcation source of a nerve. A drop of the same solution placed upon a corresponding point of the rope nearer to the other electrode may reduce, bring to zero, or reverse this difference of potential.

This phenomenon is presumably due to the upsetting of the balance between the osmotic processes taking place in the two non-polarisable and "similar" electrodes.

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7. The close association of the value of the demarcation current with the salt content of the nerve suggests a similarity between the experimental phenomena observed in the thread and in the nerve, and the causation of the demarcation current of nerve as due to a balance between two unequal osmotic processes, one at the cross section and one at the longitudinal surface.

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"The Demarcation Current of Mammalian Nerve. (Preliminary Communication.) II. The Source of the Demarcation Current considered as a Concentration Cell." By J. S. MACDONALD, B.A., L.R.C.P.E., University College, Liverpool, Research Scholar of the British Medical Association. Communicated by Professor SHERRINGTON, F.R.S. Received September 25, 1900.

The changes produced by the action of tap water upon the nerve have, in the interval, been more closely studied. Excluding alterations of E.M.F., they are as follows :—