THE ELECTRICAL CONDUCTIVITY OF PURE PROTOPLASM.

By S. C. BROOKS.

(From the Division of Pharmacology, Hygienic Laboratory, United States Public Health Service, Washington, D. C.)

(Accepted for publication, October 6, 1924.)

Measurements of the electrical conductivity of protoplasm free from interference by cell walls, vacuoles, intercellular spaces, and the like are for the first time given in this paper. Their great interest from the point of view of the study of permeability will readily be appreciated, even after due allowance is made for the fact that principles valid for one species cannot safely be generalized to include all living matter.

The organism used in the present experiments was the slime-mold, *Brefeldia maxima* (Fr.) Rost., which passes the vegetative period of its life cycle as a plasmodium creeping about in the decaying vegetable material of the swamps; when the time for spore formation approaches, the plasmodium, consisting of protoplasm containing many nuclei, flows out to the surface, forming small heaps having the consistency of very thick cream. Individual plasmodia furnish 5 to 20 cc. of an essentially pure protoplasm.[1]

Pure protoplasm of this type was placed in a U-tube of about 1 cm. diameter, the distance between the 8 mm. square platinized platinum electrodes being about 8 cm. The electrodes were sealed into glass tubes, containing the usual droplet of mercury, and the glass tubes kept in position by rubber stoppers inserted into the open ends of the U-tube. The position of the electrodes was fixed with sufficient

[1] Fixed and stained sections of plasmodia at this stage, as depicted in a paper by Harper and Dodge (Harper, R. A., and Dodge, B. O., *Ann. Bot.*, 1914, xxviii, 1) and as examined by me in the case of specimens kindly loaned by Rev. Bede Knapke show practically no vacuoles, although these appear occasionally at or near a surface on which protrusions due to already forming sporangia appear.

accuracy so that readings could be duplicated to within less than 3 per cent.

In filling the protoplasm into the U-tube a few small air bubbles were left which could not be removed without considerable stirring. This was avoided because excessive stirring was observed to lead to disorganization and liquefaction of the protoplasm. These bubbles did not in any case increase the electrical resistance by an appreciable amount, for they were never more than 2 mm. in diameter and were few in number.

The electrical resistances were measured by means of a bridge circuit with a 1 meter slide-wire provided with a 19 meter extension, and with a variable standard plug "post office box" resistance; the current was a 1,000 cycle alternating current generated by an "audio oscillator;" a telephone was used as a detector. No means of compensating for electrode capacitance was available. All measurements were at room temperature, not far from 22°C.

The resistance of water squeezed from the moss on which plasmodia were clambering was found to be 53,100 ohms; when protoplasm was filled into the same tube until it covered both electrodes the resistance was found to be 19,000 ohms. This represents a very low conductance, about equal to that of 0.00145 N NaCl, but one still greatly in excess of that of the fluid with which the protoplasm was in equilibrium. The net conductance[2] of the protoplasm of *Brefeldia* is normally about plus 180 per cent. The net conductance of red blood cells, yeast bacteria, *Chlorella*, teleost and echinoderm eggs, muscle, and of marine algæ in general, on the other hand, is usually a negative quantity; *i.e.*, their conductivity is less than that of the surrounding fluid. It is, therefore, of interest to see how *Brefeldia* plasmodium behaves under the influence of a salt concentration higher than normal.

The resistance of sea water diluted with distilled water to 1/100 of its original strength was found to be 717 ohms. The tube was then filled nearly to the level of the electrodes with protoplasm, enough of 1 per cent sea water added to more than cover the electrodes, and then worked into the protoplasm to displace the greater part of the air bubbles; the resistance was then found to be 688 ohms. It will be

[2] Brooks, S. C., *J. Gen. Physiol.*, 1922–23, v, 365.

noted that here again the resistance of the protoplasm is less than that of the surrounding fluid, although by a much smaller amount; the net conductance is here plus 4.1 per cent. This may be due to the fact that the time elapsing between the first contact with the solution and the measurement was not sufficient for the attainment of equilibrium.

The great difference in the conductance of the protoplasm in the two cases cannot be accounted for by the fact that the relatively good conductor, 1 per cent sea water, was used to displace the air bubbles in the latter experiment. Since the resistance of the protoplasm and 1 per cent sea water was less than that of the 1 per cent sea water alone, replacement of the latter by protoplasm could only decrease the resistance. In the first experiment the conductance of the protoplasm was 688/19,000 of that in the second. So low a conductance could be caused by air bubbles only if they occupied on the average more than 26/27 of the cross-sectional area. The bubbles of air certainly occupied less than 1 per cent of this area, and consequently cannot be held accountable.

The experiments therefore confirm the suggestion[2] that the conductivity of protoplasm varies with that of the surrounding fluid, thus implying permeability to electrolytes, and the existence of an equilibrium between protoplasm and environment.

The experiments here reported are admittedly of the roughest kind, and can only be considered as preliminary; but they are not only of intrinsic interest, but suggest further experiments which should be most instructive. These the writer hopes to take up at an early opportunity.

SUMMARY.

The electrical conductivity of the plasmodium of the slime-mold *Brefeldia maxima* (Fr.) Rost., which constitutes practically pure protoplasm, was found to be approximately equivalent under normal conditions to that of a 0.00145 N NaCl solution, and about 2.8 times that of the liquid in contact with which it developed.

When bathed in 1 per cent sea water, the conductivity was much increased, becoming greater than that of the surrounding fluid.

These preliminary tests are in agreement with the supposition that the protoplasm is permeable to and in equilibrium with its environment in so far as electrolytes are concerned.

This work was done at the Marine Biological Laboratory, Woods Hole, with facilities and apparatus kindly made available by the Laboratory and by Dr. Maurice Visscher, and to both the writer wishes to express his indebtedness and thanks.