VARIATION OF THE ELECTRIC RESISTANCE OF PLANT TISSUES FOR ALTERNATING CURRENTS OF DIFFERENT FREQUENCIES DURING DEATH

By BASILE J. LUYET

(From The Biological Laboratory, Cold Spring Harbor, Long Island)

(Accepted for publication, November 21, 1931)

The study of the electric resistance of living cells, in relation to variation of frequency of alternating current, developed during the last 20 years by Höber (1910), Gildemeister (1919), Philippson (1920), Waterman (1922), Fricke (1923), McClendon (1924), Fricke and Morse (1925), Blinks (1928), and Remington (1929), has been used chiefly in determining physical characteristics of various tissues such as muscle, liver, skin, red corpuscles, plant cells and in special investigations on subjects such as the resistance of malignant tumors; but such problems of general physiology as growth or death, in relation to variation of frequency, remain almost untouched. Therefore, since the method seemed promising, I undertook the present study of the variation of the resistance of a plant tissue which was injured or killed by heating or freezing or by the action of poisonous substances.

Apparatus, Material, and Working Methods

The measurements were made with the high frequency bridge described by H. Fricke (1925*a*, 1925*b*), and Fricke and Morse (1925, 1926). The frequencies used vary from 0.5 to 1024 kilocycles.

The conductivity cell is of the same kind as that described by Fricke (1926). The tissue is fastened in the hole of an isolating diaphragm of celluloid which divides into two parts a solution of KCl in which the platinized platinum electrodes are immersed. The hole is cylindrical and measures 1/4 of an inch in diameter and 1/8 of an inch in length.

The piece of tissue to be placed in the hole is cut with a cylindrical borer which has an inside diameter of 0.266 inch. After being fastened in the hole, both ends of the piece are shaved with a razor blade. In experiments in which the tissue is to be injured it is cut 1/2 inch in length and a borer with an inside diameter of 0.400 inch is used instead of the one referred to above. Then after being treated

it is recut to fit in the hole. An exact fit is impossible if the tissue is cut to size before treating, because of the contraction or softening which takes place.

When a tissue is placed in a salt solution its resistance may change continuously. If the external solution is concentrated the resistance decreases, if dilute it increases, while an intermediary concentration gives an almost constant resistance. Several solutions with different concentrations were tried in my experiments. KCl M/25 was selected as giving the best results during the 30 minutes necessary for the readings.

As the material for experimentation, I chose *Ambrosia trifida*. I used plants young enough and pieces close to the tip (3 to 20 cm.) in which the pith had not yet begun to show a white opaque appearance and where there was little lignification. The pieces used in the same experiment were cut from the same stem and as near to each other as possible. They were always cut in such a way that the direction of the current was parallel to the axis of the stem.

The tissue was heated by immersion in a KCl M/25 solution previously warmed to the desired temperature. Freezing was performed in a cylinder of thin brass buried in carbon dioxide snow. After having been warmed or frozen, the tissue was, of course, brought back to the usual temperature for the electric measurements. Injuring with chemicals was produced by immersion. Tissues were then washed rapidly and put in the conductivity cell.

DATA

Resistance of Tissue Injured by Heating (50°), Boiling, Freezing (CO_2) and by the Action of Ether and Alcohol (95 Per cent)

(Frequency in kilocycles; Resistance in ohms of a cube 1 cm. on each side)

Frequency	Normal tissue	2 min. 50°	4 min. 50°	6 min. 50°	Boiled tissue	10 sec. CO_2	10 min. ether	2 min. alcohol
0.5	871	602	325	263	157	508	428	395
1	862	565	324	263	154	518	425	391
2	840	552	322	258	153	521	424	386
4	823	554	306	262	148	500	423	385
16	722	518	298	253	143	471	393	361
32	549	499	286	250	143	445	343	342
64	355	375	269	239	143	380	262	301
128	253	299	228	237	142	282	193	273
256	168	212	206	233	136	196	130	234
512	125	163	194	221	129	134	94	199
1024	90	113	179	214	130	102	81	198

DISCUSSION

1. At low frequencies the resistance decreases with the increase of the injury until it reaches a minimum which is the resistance of dead

tissue (this effect has been extensively studied by Osterhout). At high frequencies the resistance of dead and living tissues is nearly the same and its value approaches that of dead tissue with low frequency.

2. The preceding facts are in agreement with the idea that the electrical resistance of tissues under experiment is due mostly to the sur-

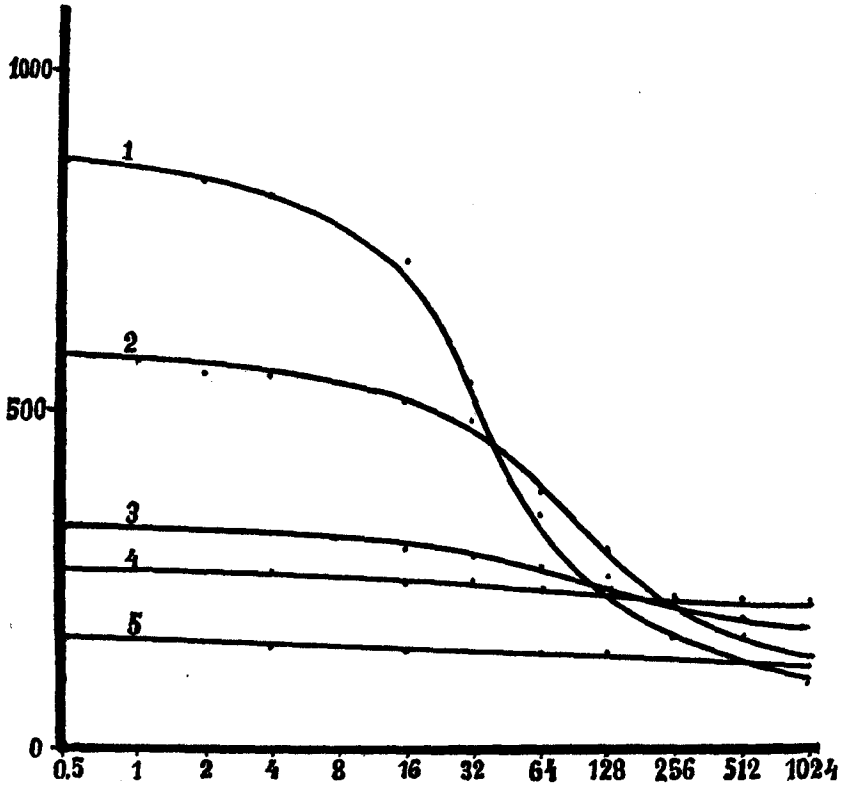

FIG. 1. Resistance of the plant tissue (1) under normal conditions, (2) heated 2 minutes at 50°C., (3) heated 4 minutes at 50°C., (4) heated 6 minutes at 50°C., and (5) boiled 20 minutes. Abscissae: Log of frequencies in kilocycles. Ordinates: Resistances in ohms.

faces of the cells. It is well known that injury and death are accompanied by a more or less complete destruction of these surfaces. The decrease in resistance at low frequencies seems to correspond to the degree of this destruction. On the other hand it is well known that resisting films have less effect the higher the frequency of the current,

so the results at high frequencies also agree with the preceding assumption.

3. Is the drop of resistance following the injury due to an increasing number of damaged cells or to an increasing permeability of all the cells? This cannot be decided by my experiment.

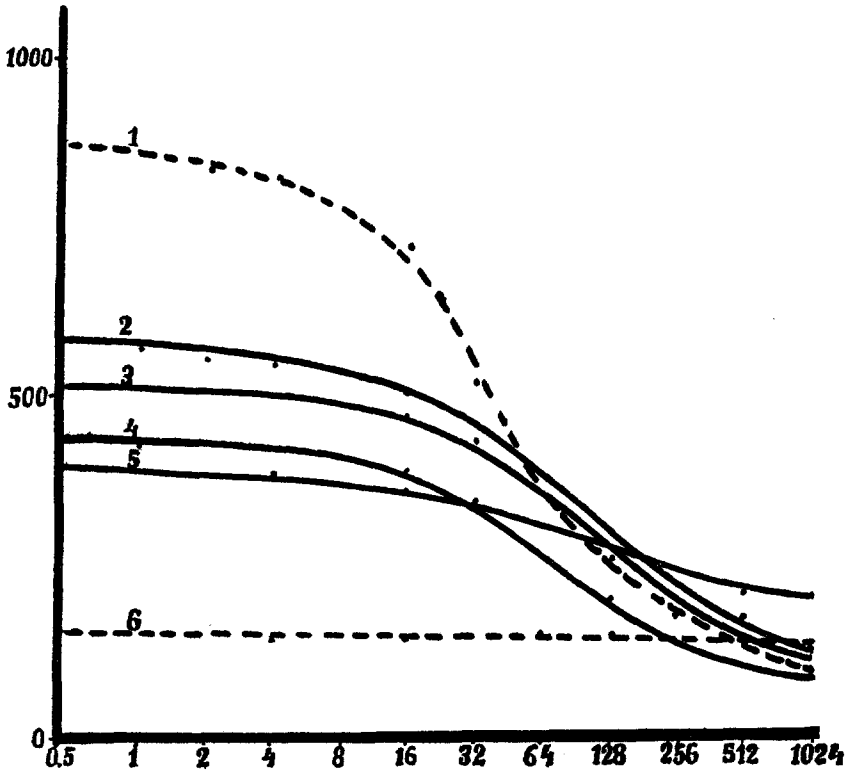

FIG. 2. Resistance of the plant tissue (1) under normal conditions, (2) heated 2 minutes at 50°C., (3) plunged 10 seconds in solid CO_2, (4) plunged 10 minutes in ether, (5) plunged 2 minutes in alcohol (95 per cent), and (6) boiled 20 minutes. Abscissae: Log of frequencies. Ordinates: Resistances in ohms.

4. It will be noticed that the difference of time of exposure necessary to produce a complete drop of resistance (until the resistance of dead tissue is reached) and to produce any other sign of death is enormous. A few minutes at 50°C. are enough to make the resistance

drop to its limit, whereas hours are necessary to produce any sign of death with usual indicators or to change the turgor or to make noticeable the characteristic color of killed plant tissue.

5. An injury by ether behaves in the same way as an injury produced by heating or freezing, both processes showing parallel curves (Fig. 2, Curves 2, 3, and 4). Alcohol (Fig. 2, Curve 5) shows a somewhat different curve.

I express my gratitude to Dr. H. Fricke, Dr. W. Osterhout, and Dr. R. Harris for their valuable suggestions.

BIBLIOGRAPHY

Blinks, L. R., *Science*, 1928, **68**, 235.

Brooks, S. C., *Proc. Soc. Exp. Biol. and Med.*, 1922, **19**, 284; *J. Gen. Physiol.*, 1923, **5**, 365; 1925, **7**, 327.

Cole, K. S., *J. Gen. Physiol.*, 1928, **12**, 32.

Crile, G. W., Hosmer, H. R., and Rowland, A. F., *Am. J. Physiol.*, 1922, **59**, 458.

Fricke, H., *Phys. Rev.*, 1923, **32**, 708; 1924, **25**, 575; 1925*a*, **26**, 682, *J. Gen. Physiol.*, 1925*b*, **9**, 137.

Fricke, H., and Morse, S., *J. Gen. Physiol.*, 1925, **9**, 153; *J. Cancer Research*, 1926, **10**, 340.

Gildemeister, M., *Arch. ges. Physiol.*, 1919, **84**, 176; 1928, **89**, 219.

Höber, R., *Arch. ges. Physiol.*, 1910, **133**, 237; 1912, **148**, 189; 1913, **150**, 15.

McClendon, J. F., *Science*, 1924, **60**, 204; *J. Biol. Chem.*, 1926, **69**, 733; *Am. J. Physiol.*, 1927, **82**, 525; *Proc. Soc. Exp. Biol. and Med.*, 1927, **25**, 202.

Osterhout, W. J. V., Injury, recovery and death in relation to conductivity and permeability, Philadelphia, J. B. Lippincott Co., 1922.

Philippson, M., *Compt. rend. Soc. biol.*, 1920, **83**, 1399; *Bull. Acad. roy. Belgique*, 1921, **7**, 387; *Arch. internat. Physiol.*, 1921, **18**, 161; *Bull. Soc. belge biol.*, 1924, **1**, 373.

Mendeleef, P., *Compt. rend. Soc. biol.*, 1926, **94**, 1277.

Remington, R. E., *Protoplasma*, 1929, **5**, 338.

Waterman, N., *Biochem. Z.*, 1922, **133**, 535.