

hydrolysis, and that part of the coal substance consists of 'humic humates'.

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Membrane Electrophoresis in Relation to Bioelectrical Polarization Effects

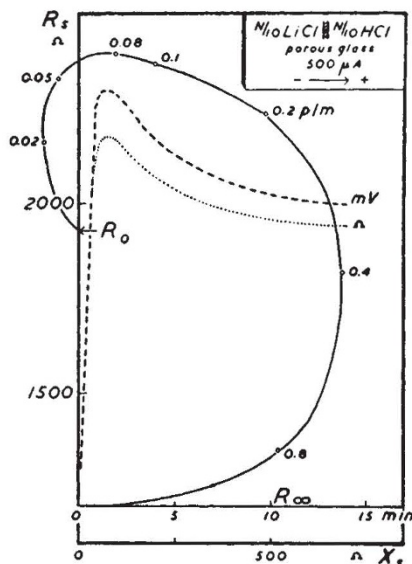
IN electrophysiology the term 'polarization' often has an ambiguous meaning. Here it will be used in the physical sense as an overall definition to include changes in the 'resting potential' of the object (membrane, nerve, skin, etc.), as well as the appearance of rectification, capacity and inductivity effects under the influence of an externally applied current. The potential changes and the rectification effects have mostly been interpreted in a qualitative manner in terms of selective ion permeability, and the capacity as 'double layers', 'dielectrics', etc.^{1,2,3}. Cole⁴ has recently made the unexpected observation of an inductance component in the squid axon, which he seems inclined to explain as analogous to piezoelectric behaviour. Lorente de N6⁵ prefers more unspecific concepts implying also chemical reactions.

A very simple system, which can display the characteristic features of polarization, is:

Homogeneous mass (1)	Porous membrane	Homogeneous mass (2)
$A+R^-$	$A+R^- + B+R^-$	$B+R^-$

If the mobility of the ion constituent B^+ is greater than that of A^+ , then the application of direct current, with the direction (1) anode and (2) cathode, will decrease the conductivity within the membrane. A reversed current direction will increase it; thus the 'rectification' may be easy enough to understand. The membrane behaves as a non-linear circuit element. Obviously this type of electrolyte system is closely related to the well-known 'moving boundary' systems. Theories⁶⁻¹¹ and experiments^{12,13} show that the transition layer between masses (1) and (2) under appropriate conditions can be segregated in successive layers with different ionic compositions, which can move in either direction. These concepts can easily make understandable the fact that a membrane, supporting electrolytes, can change its longitudinal conductivity in a non-linear fashion. A great variety of patterns of the interrelations between direction, density and duration of the applied current and the resulting conductivity can be anticipated. The changes of the conductivity (and membrane potential proper) may lead to voltage vs. time curves similar to those known from the transient responses on rectangular D.C. pulses, applied to circuits containing resistances, capacities and inductivities.

The accompanying graph provides an example taken from a preliminary study. A system 0.1 N lithium chloride (stirred)/porous glass membrane/0.1 N hydrochloric acid (stirred) was subject to constant current flow with the cathode on the hydrochloric acid side. The change of the total membrane voltage with time exhibits an 'overshooting' (see the dashed curve, mV) well known from certain RLC (or RC) circuits. The parallel course of the high-frequency resistance of the membrane layer (dotted curve, Ω) indicates that the temporal variation of the potential is, in the main, caused by changes of the electrolyte content within the membrane (the membrane potential proper, that is, the 'back-E.M.F.',



plays a minor part here). The voltage-time curve has also been transformed into an a.c. 'impedance locus diagram' by the aid of 'square wave analysis'¹⁴. The locus curve (full line) of the impedance at different a.c. frequencies is of the shape regarded as typical for a resistance-capacitance-inductance circuit (cf. ref. 15).

In conclusion, it may be stated that a purely aqueous electrolyte system may exhibit effects formally similar to rectification, capacity and inductivity. Changes of the 'resting potential' or 'back E.M.F.' can also be demonstrated, especially with charged membranes. All phenomena are due to ionic redistributions within the membrane, initiated by the flowing current. These observations may have bearings on discussions on the nature of biological polarization phenomena. More experimentation under well-controlled conditions seems desirable. Theories of electrolytic migration also require extension to include the effects of diffusion, membrane dimension, membrane charge, solvent movement, etc. Investigations in these directions are being made in this laboratory.

This type of moving-boundary can obviously be utilized as an electrophoresis method for separation purposes, particularly if a superposed counter-flow of the solvent is employed.

An extended report of this work will be published elsewhere.

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³ Cole and Curtis, *J. Gen. Physiol.*, **24**, 551 (1941).

⁴ Cole, *J. Gen. Physiol.*, **25**, 29 (1941).

⁵ Lorente de N6, Harvey Lectures Series, No. 42, 43 (1946-47).

⁶ Kohlrausch, *Ann. Physik.*, **62**, 209 (1897).

⁷ Weber, "Die partiellen Differential-Gleichungen d. matem. Physik.", **1**, 424 (Braunschweig, 5 Aufl., 1910).

⁸ MacInnes and Longworth, *Chem. Rev.*, **11**, L72 (1932).

⁹ Longworth, *J. Amer. Chem. Soc.*, **67**, 1109 (1945).

¹⁰ Dole, *J. Amer. Chem. Soc.*, **67**, 1119 (1945).

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¹² Longworth, *J. Amer. Chem. Soc.*, **65**, 1755 (1943).

¹³ Longworth, *J. Amer. Chem. Soc.*, **66**, 449 (1944).

¹⁴ Teorell, T., *Acta Physiol. Scand.*, **12**, 235 (1946).

¹⁵ Cole, *J. Gen. Physiol.*, **24**, 771 (1941).