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# Induced emf in Electrolytes

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USUALLY the effect of an electric field on the movement of ions in electrolytes is studied by direct application of the field by means of electrodes. It is of interest to expore the interaction between an induced electric field and ions in solution. Maxwell's law relating changing magnetic flux and electric field intensity is

$$(d/dt)\int_s \mathbf{B}\cdot d\mathbf{a} = -\oint_c \mathbf{E}\cdot d\mathbf{s},$$

where $d\mathbf{s}$ is an element of length along, and $d\mathbf{a}$ an element of area $\mathbf{s}$ enclosed by contour $c$. Faraday's experiments on induction, carried out with metallic circuits, led Maxwell to the theoretical formulation of the phenomenon. Maxwell's point of view was abstract and he defined his law for any arbitrary loops of conductors or nonconductors.[1]

The passage of current through electrolytes involves ionic transport. Since this differs from electron movement in metals, we wished to study the effect of a slowly varying magnetic flux on the induction of electric fields in solutions, where the following points should be noted: (a) Positive and negative charges are present and move simultaneously in opposite directions; (b) Ions have single or multiple charges and a mixture of ions may be present; (c) concentrations of ions can be varied; (d) the mechanism of ionic movement may differ (protons).

To study experimentally the effect of magnetic induction on ions in solution, an electric transformer (110 v ac) was modified. The primary winding was left intact but the secondary was removed. Two new windings were substituted: (a) a long piece of Tygon tubing (internal diameter 3 mm) wound around the iron core with both ends connected to glass funnels, or (b) a copper wire wound around the same iron case (reference winding). Tygon tube winding and funnels were filled with suitable electrolyte and platinum electrodes placed in the funnels. A 60-cycle alternating potential was applied to the primary winding and following measurements were made: primary current, primary potential, secondary potential, secondary winding resistance (electrolyte). Since resistance of the coil was high when it contained dilute electrolyte, secondary potentials had to be measured with a high input impedance vacuum tube voltmeter. Waveform was followed with an oscillograph. A series of measurements were carried out in different electrolytes (HCl, NaCl, KCl, $CuSO_4$, $H_2SO_4$) at various concentrations. The results can be summarized as follows: (a) the secondary potential induced in electrolyte does not depend on the character of the electrolyte and its concentration (provided that the potential is measured correctly at high dilutions); (b) there is no visible change in the sinusoidal wave form of the potential of the electrolyte coil provided that magnetic saturation of the iron core is avoided; (c) there is no phase shift when the potential of the electrolyte and the copper winding are compared.

Subsequently windings were reversed and potential was applied to the electrolytic coil which served as the primary. Induced potential in copper-secondary was again sinusoidal and its magnitude was proportional to the applied primary potential. This proves that ionic and protonic currents in electrolytes will induce emf in magnetically coupled metallic circuits. However, it is expected that differences in ionic and electronic movements will appear, when the frequency of varying magnetic flux is in the range of time of relaxation for ionic motion. Because of large energy losses at high frequencies in iron core, such experiments could not be carried out.

Our experiments confirm Maxwell's law of induction as valid in electrolytic media since the induced potential does not depend on (a) the magnitude and polarity of charges, (b) the velocity of charges, (c) the character of medium, or (d) the mechanism of charge transport (protons). The equivalence of electric and magnetic fields in certain geometric relations seems to be indicated.

One interesting feature of the induced potential is that an alternating potential can be produced in an electrolyte without electrodes. This may sometimes be desirable in certain experimental conditions, e.g., the elucidation of the mechanism of proton movement. It has been suggested[2] that the preferred direction of proton movement in water results from the proton sink at the cathode and not from an orientation of the water molecules and hydrated protons in the external electric field. By using an electrolytic transformer, a selective experiment was made. The electrolytic coil which contained $1M$ HCl solution served as secondary winding. Potential was applied to the primary and secondary current and was measured by a Clipp-On ac Microammeter (Quan-Tech, Model 301). The secondary coil was at first short circuited by an electrolytic bridge ($1M$ HCl) and then by the metallic electrodes. Current values were the same for both cases. This suggests that the preferred direction of proton movement in water does not result from the proton sink at the cathode.

[1] J. C. Maxwell, *A Treatise on Electricity and Magnetism* (Oxford University Press, New York, 1892), 3rd ed., Vol. II.
[2] G. Kortum and J. O'M. Bockris, *Textbook of Electrochemistry* (Elsevier Publishing Company, New York, 1951).