Contact Potentials for Metals Immersed in a Dielectric and Conduction of Electricity by Liquid Dielectrics

Recent papers by Baker and Boltz[1, 2] and by K. H. Reiss[3, 4] have focused attention on the old problem of the origin of the electrical conductivity of pure nonpolar dielectric liquids. The problem falls naturally into two parts. The first involves the explanation of the "saturation," or field-independent current which is observed under fields up to 25 to 100 kv per cm, depending upon the liquid. The second is concerned with the explanation of the current at higher field strengths, which is approximately an exponential function of the applied stress.

At the present time, there are three theories which purport to explain the high field phenomena. These are (1) the ionization by collision theory of A. Nikuradse,[5] (2) the potential-dissociation theory of K. H. Reiss,[3] and (3) the thermionic emission theory of Edler and Zeier[6] and Baker and Boltz.[1] It is the purpose of this note to describe experiments which are entirely inconsistent with this third theory of dielectric conduction.

According to Baker and Boltz, the current flowing in a liquid dielectric is governed by Schottky's modification of Richardson's equation, the dielectric constant D of the liquid being introduced as a correction:

$$I = AT^2 e^{-\epsilon\phi/kT} e^{\epsilon(\epsilon FD)^{\frac{1}{2}}/kT}.$$

In this equation, ϕ represents the work function of the metal when immersed in the dielectric. This is an unknown quantity. Now if two dissimilar metals with metal-dielectric work functions of ϕ_1 and ϕ_2 are used as electrodes, we obtain at once from this theory the ratio of the currents I_1/I_2 with the first and the second metal respectively serving as cathode:

$$I_1/I_2 = e^{-\epsilon(\phi_1-\phi_2)/kT}.$$

The quantity $\phi_1-\phi_2$ is simply the contact potential between the two metals when immersed in the dielectric. In order to check this prediction of the theory, an experiment was conducted in which the contact potential between gold and brass electrodes immersed in highly purified iso-octane was determined by a modified Kelvin method and subsequently the ratio of the high field currents in the liquid in the two directions.

The electrodes were ground optically flat so that it was possible to bring them into very close proximity (of the order of thousandths of a millimeter). Under these conditions contact potentials could be very accurately determined with a very slight displacement of one electrode. The experiment was conducted in vacuum and an FP-54 amplifier was used to detect the potential changes as well as to measure the currents in the second part of the experiment.

The contact potential between gold and brass was found to be 0.255 volt in vacuum and 0.265 volt in iso-octane. With the value of 300°K for the temperature, the predicted value of I_1/I_2 was calculated to be 30,100 where I_1 and I_2 are the currents with the brass and gold electrodes respectively acting as cathodes.

The results of an actual experiment are given in Table I. The field strength F is given in volts per cm and the currents in amperes per square cm.

TABLE I. *Currents between brass and gold electrodes in iso-octane. F is the field strength in volts per cm. I_1 and I_2 are the currents with the brass and gold electrodes respectively as cathodes.*

F (v/cm)	I_1	I_2	I_1/I_2
10,000	1.2×10^{-13}	1.2×10^{-13}	1.00
75,000	4.0×10^{-13}	4.2×10^{-13}	.95
130,000	2.1×10^{-10}	2.0×10^{-10}	1.05
175,000	1.5×10^{-9}	1.3×10^{-9}	1.15

It is evident that the current ratio is unity within experimental error. It is definitely not of the order of magnitude of 30,000 as required by the thermionic emission theory. This same sequence of experiments was carried out with several highly purified mineral oils and the same results were always obtained, i.e., the current ratio was always very near unity. It must be concluded that the thermionic emission theory is inadequate to explain the conductivity of the dielectrics used in these experiments.[7]

It should be noted that there also exist very serious objections to the other two previously mentioned theories of liquid dielectric conduction. It would seem that up to the present time, no satisfactory explanation of the phenomena has been found.

The contact potential difference between gold and brass immersed in several other liquids was determined and in every case its value was very near the value as measured in vacuum. If the liquid be conducting in the slightest degree, one should no longer speak of the contact potential between two metal surfaces immersed in the liquid except in the sense that the liquid itself in this case will assume a contact potential with reference to each metal surface.

This will be true with even the most perfectly insulating liquids if sufficient time in contact is allowed for the attainment of equilibrium. A complication in the case of nonpolar liquids with slight traces of impurities is the presence of an electrochemical e.m.f.

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[1] E. B. Baker and H. A. Boltz, Phys. Rev. **51**, 275 (1937).
[2] E. B. Baker and H. A. Boltz, Phys. Rev. **51**, 989 (1937).
[3] K. H. Reiss, Zeits f. physik. Chemie **178**, 37 (1936).
[4] K. H. Reiss, Phys. Rev. **51**, 781 (1937).
[5] A. Nikuradse, Physik. Zeits. **34**, 97 (1933).
[6] H. Edler and O. Zeier, Zeits. f. Physik **84**, 356 (1933).
[7] The conductivities observed by Baker and Boltz seem rather high. A possible explanation is that they distilled their toluene over sodium. This is known to be a dangerous practice since sodium phenyl, a relatively good conductor, may be produced. We were unable to measure contact potentials in toluene, which had been purified in this manner, due to the presence of electrochemical e.m.f.'s.

Solar Diurnal Variation of Cosmic-Ray Intensity as a Function of Latitude

Exceptional opportunity for the study of the solar diurnal variation of cosmic-ray intensity at various latitudes is offered by data obtained by A. H. Compton and R. N. Turner on eleven trips between Vancouver, B. C., and Sydney, Australia on the Canadian-Australasian motorship Aorangi from March 1936 to January 1937. There are presented here the results of a preliminary survey of these data and an outline of the method used in obtaining them.