THE ELECTROMETRIC MEASUREMENT OF THE VOLTAIC POTENTIAL DIFFERENCE, BETWEEN THE TWO CONDUCTORS OF A CONDENSER, CONTAINING A HIGHLY IONIZED MEDIUM.

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1. *Introductory.*—The difficulties encountered in the preceding paper (§ 4), were made the subject of direct investigation by replacing the fog chamber with a metallic cylindrical condenser, the core of which was an aluminum tube, 50 cm. long and .63 cm. in diameter, the shell a brass tube, 50 cm. long and 2.1 cm. in diameter, coaxial with the former. Sealed radium tubelets could be placed within the aluminum tube, or withdrawn from it. Moreover, either the outer coat or the core of the condenser could be joined in turn with the Dolezalek electrometer, the other being put to earth. The conducting system now appears as follows (Fig. 1), *C* being the outer coat or brass shell, *A* the aluminum core and *r* the radium tubes in the cylindrical core. Conductors are earthed at *e*. *BB* show the metallic connections with the auxiliary condensers *C′*, *C″*. *E* is one of the insulated quadrants of the electrometer with the highly charged needle *N*, *E* being virtually also a condenser.

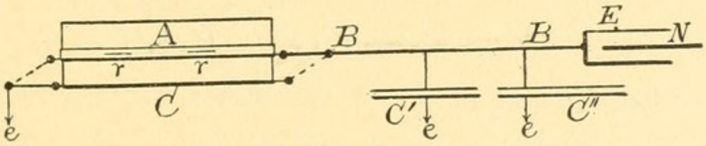


Fig. 1

A Clark standard cell may be inserted for standardization, but it is otherwise withdrawn.

Direct experiment showed the self charging tendencies to come apparantly from the highly charged needle *N*, as if positive ions were loged into the conductor *EBBA* for a positive needle, negative ions for a negative needle. In addition to this however there is a *voltaic* difference, aluminum-brass, at AC when radium is in place and the medium therefore highly ionized. The latter potentials are usually negligible. These are the chief electromotive forces, the first very high (150 volts) and in a weakly ionized medium; the other low (.2 volt) but in an intensely ionized medium: thus they may produce equal currents. Other voltages such as the room potential may be operative, but their effect is secondary. If the capacities C', C'', are successively removed the electrometer current increases proportionately, showing its origin to be directed from the needle toward the insulated or non-earthed pair of quadrants.

If the condenser metals are reversed (see Fig. 1), the voltaic couple is reversed. This makes it possible to obtain both the voltaic contact potential and the ionization in the condenser C, from a pair of commutated measurements.

2. *Theory.*—Let V_n be the potential at the electrometer, V_c the voltaic potential difference of the two metals of the condenser, V the potential of the insulated conductor BB, measured by the electrometer. Let n be the hypothetical ionization in the electrometer, N the (radium) ionization in the condenser (length l, radii R_1, R_2). Let C be the total capacity of the systems $CBBE$. Then

$$\dot{V} = A(V_n - V)n - \frac{600\pi lNev}{C \ln R_1/R_2}(V - V_c)$$

where A is a constant, u and v the normal velocities of the positive and negative ions, e the charge of the electron. The needle is positively charged. This may be written

$$\dot{V} = \dot{V}_a - K(V - V_c),$$

where for $N = 0$, $K = 0$, or

$$\dot{V} = \dot{V}_a = A(V_n - V)n,$$

i. e., the current in the electrometer, observed in the absence of radium, from needle to quadrants. This is directly measurable with accuracy. It is nearly proportional to V_n since V is much within 1 per cent. of V_n.

The integral of this equation is, t being the time,

$$V = (\dot{V}_a/K)(1 - KV_c/\dot{V}_a)(1 - e^{-Kt}).$$

If now the needle is left positively charged, but the condenser metals exchanged (commutated), so that the aluminum core is earthed and the shell put in contact with the electrometer (see figure), the equation becomes

$$V' = (\dot{V}_a/K)(1 + KV_c/\dot{V}_a(1 - e^{-Kt}).$$

Let $\kappa = N/K$ and $\kappa' = N/K'$ where K' refers to the normal velocity of positive ions, u. Then if $k = V_c/\kappa\dot{V}_a$, and $k' = V_c/\kappa'\dot{V}_a$, similarly

$$\dot{V} = \dot{V}_a(1 - kN)e^{-Kt}.$$

$$\dot{V}' = \dot{V}_a(1 + kN)e^{-Kt}.$$

If the potential $V = V_\infty$ at $t = \infty$,

$$V_\infty = \kappa\dot{V}_a/N - V_c,\ V_\infty' = \kappa\dot{V}_a/N + V_c,$$

two equations from which both N and V_c may be found, if the limiting potentials V_∞, V_∞', and the electrometer current $\dot{V}_a$ are severally observed. If V_∞ is not obtainable, it may be computed from observations at t and $t_1 = 2t$, as

$$V_\infty = (2V - V_1)/V^2 \text{ and } V_\infty' = (2V' - V_1')/V'^2.$$

Here however there is a difficulty as the curves begin with a double inflection not yet expained. The times $t_1 = 2t$ must therefore be estimated from the observations beyond the double inflections; or the rearward prolongation of the curve for those observations, to meet the time axis. The initial tangents may be found in the same way, but this is not necessary since their values are, respectively,

$$\dot{V}_a(1 - kN) \text{ and } \dot{V}_a(1 + kN).$$

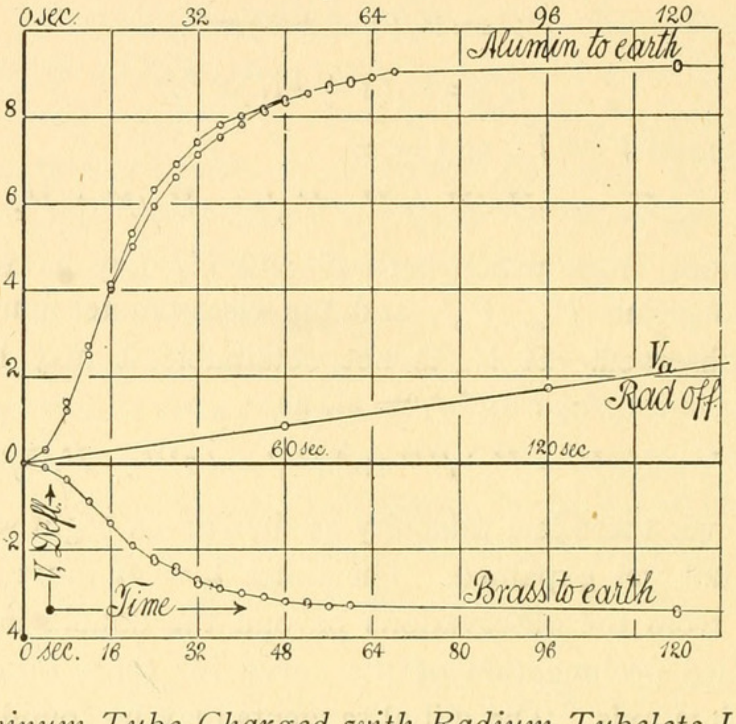
3. *Data: Origin of the Electrometer Current.*—The seat of the chief electromotive force in the electrometer follows from the following data, in which the capacities C, C', C'', Fig. 1, are successively removed. The currents increase in the same ratio as the reduction of capacities, E being that of the electrometer. The data are (potentials in scale parts where 1 cm. is equivalent to .0595 volt), $\dot{V}_a$ being the fall per second:

Capacities.	$\dot{V}_a$ in cm.	$\dot{V}_a$ in Volts.
$C + C' + C'' + E$	.14	.0083
$C' + C'' + E$	.15	.0089
$C' + E$	.58	.0345
E	4.3	.256

The change of voltage throughout the main contours of the curves is almost a linear variation with the lapse of time, except that at the beginning the motion is accelerated from rest as usual; for instance:

Time	0	4	8	12	16	20	24	28	32	60 sec.
V_a	0	.3	1.5	3.7	6.1	8.7	11.0	13.4	15.5	31.0 cm.

Fig 2



4. *Aluminum Tube Charged with Radium Tubelets I.–V.: Data.* —The air in the condenser C is now highly ionized and its voltage becomes appreciable. The data obtained are given in Fig. 2. The needle is positively charged, thus impelling positive charge toward the quadrants. In the four series of data observed the aluminum core of the condenser is twice joined to the electrometer, the brass shell being put to earth (series 1 and 4) and twice commutated (aluminum to earth series 2 and 3). The results are identical except that in series 3 the insulation was perhaps better, or V_a may have changed. The accelerated march of the needle from rest is obvious in both curves and is thus independent of the sign of the limiting voltage, V . It may be mere inertia, but it is of less consequence here because the initial data are not needed in the following computation.

5. *Results: Ionization, N. Voltaic Contact Potential Difference*[1] V_c.—The equations

$$V_c = \kappa V_a/N - V \ ,$$
$$-V_c = \kappa V_a/N - V_\infty',$$

may now be used to compute N and V_c. The constants are numerically (all in scale parts, 1 cm. equivalent to .0595 volt),

$$\kappa = 36.1 \times 10^6, \quad V_\infty = -3.45, \quad V_a = .142$$
$$\kappa' = 39.7 \times 10^6, \quad V_\infty' = 9.3,$$

Hence

$N = 876{,}000$ ions, either positive or negative,
$V_c = 6.37$ cms., or .376 volts.

[1] [The drift, V_a, which in the above experiments was eliminated by commutation, was eventually traced to a defect in the electrometer. It vanishes on replacing the given instrument by another. Data since obtained for Aluminium-Copper and Aluminium-Zinc condensers showed

Al-Cu, $V_c = .58$ volts,

Al-Zn, $V_c = .06$ volts,

or

Zn-Cu, .52 volts,

a result, however, which varied much with the surfaces, etc.] June, 1909.

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