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Electromotive force and internal resistance of dark electric current in liquid

S.A. Gerasimov
Department of General Physics, Southern Federal University, Rostov-on-Don, 344090, Russian Federation

Abstract: *Superposition of net electromotive force (e.m.f.) arising without external optical influence in clean water with three immersed aluminum electrodes enables to solve inverse problem, that is to say, to obtain the electromotive forces created by each pair of the electrodes. The net e.m.f. is found to be of the order of 0.2 V. The electric current is about 0.1 mA. Internal resistance of each pair of electrode is less than 10 k*Ω*. These results follow from experimental data obtained after measuring the load resistance dependencies for various sizes of the intermediate electrode. The dependences of e.m.f. and the liberated power on sizes of electrodes are discussed.*

Key Word*: Dark electric current; Electromotive force; Aluminum; Water; Electric Energy, Voltage.*

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I. Introduction

Behavior of a source of electric energy is easily enough understood if it is know of what it consists. If metal is aluminum and water is clean that a thin layer of aluminum oxide on its surface suppresses chemical reactions of the aluminum electrodes with water. On the other side, the aluminum oxide layer is too thin that particles of the metal and the water can pass through a potential energy barrier of the layer that is higher than the energy of the particles [1]. A tunneling current therefore can flow through the contact of aluminum with water. Although this might seem strange at first, it is easily justified experimentally.

The first law of thermodynamics places no restriction on the direction of the process, and satisfying the first law does not guarantee that the process will occur. Therefore the electrodes immersed in the liquid must be asymmetrical. The second law of electrodynamics asserts that the current can occur at the temperature difference between electrodes. Since the tunneling is quantum process, the principle of nondecreasing entropy can be violated [2]. One should also take into account that the system consisting of a volume of the liquid with electrodes and external equipment is not equilibrium [2].

With no external optical and other influences, beside, may be, heat, such a *dark* electric current really flows unlimited time in a resistor connected to cylindrical aluminum electrodes immersed in distilled water [3]. When increasing sizes of the system, this dark current achieves of the order of 0.1 mA with dissipated power of the order of 10^{-5} W [4]. Appropriate to notice that the energy dissipated within 24 hours is sufficient to lift a body of mass of 0.09 kg through the high of 1 m.

In physics and in electronic engineering, usual dark current is very small electric current that flows through photosensitive devices such as a photomultiplier tube, photodiode, or charge-coupled device even when no photons are entering the device. It consists of the charges generated in a usual photoelectric device when no outside radiation is entering the photosensitive detector [5]. The liquid with two immersed electrodes can also play role of the photoelectric cell. In studying the photoelectric current in liquids, experiments frequently encounter deviations from the known photocurrent-illuminance characteristics: the voltage is found to be proportional to neither the luminosity nor the temperature of the liquid [6]. In order to improve these parameters one should find out what creates such a considerable energy. Apparently needed one more electrode which will enable to know what happens in the liquid between aluminum electrodes.

II. Three measurements of dark electric current in liquid

The problem can be solved after measuring the voltage U_{kj} on the load of resistance R connected to various electrodes of three-electrode source of the dark electric current shown in Fig. 1. This is three axisymmetric aluminum cylinders C_1, C_2 and C_3 with radii c_1, c_2 and c_3, respectively, of thickness of 0.1 mm and the high of H=18 cm is partly immersed in distilled water L. The depth of immersion h is 14 cm.

One may consider this source of current as three sources of electromotive force (*e.m.f.*) two them (E_{12} and E_{23} with internal resistances r_{12} and r_{23}) are joined in parallel to the E_{13} with an internal resistance r_{13}. It is impossible to break this connection, the only way, therefore, to determine electromotive forces E_{kj} is to measure voltages on the external load of resistance R joined in parallel to each pair of the electrodes C_1, C_2 and C_3.

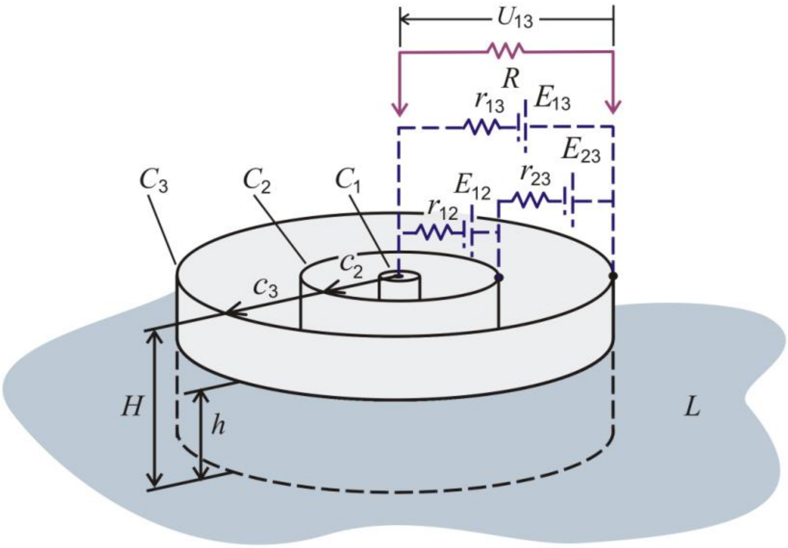


Fig. 1. Three cylindrical electrodes in liquid and their equivalent electromotive forces

For the first connection (k=1, j=3) shown in Fig.1 the equivalent *e.m.f.* and the internal resistance are

$$E_1 = \frac{(E_{12} + E_{23})r_{13} + E_{13}(r_{12} + r_{23})}{r_{12} + r_{23} + r_{13}}, \quad (1)$$

$$r_1 = \frac{r_{13}(r_{12} + r_{23})}{r_{12} + r_{23} + r_{13}}, \quad (2)$$

therefore, the load resistance dependence of the voltage U_{13} can be described be a linear dependence of $1/U_{13}$ versus $1/R$

$$\frac{1}{U_{13}} = b_{13} + a_{13}\frac{1}{R}, \quad (3)$$

where

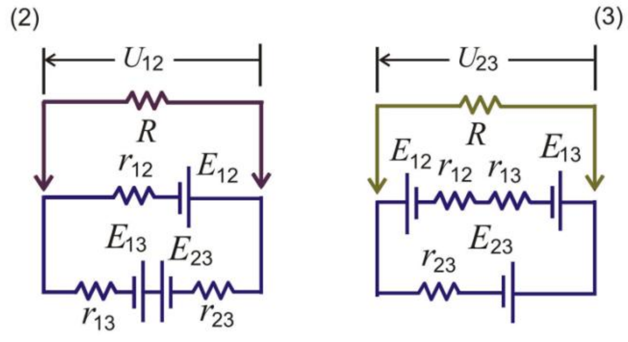
$$b_{13} = \frac{r_{12} + r_{23} + r_{13}}{(E_{12} + E_{23})r_{13} + E_{13}(r_{12} + r_{23})}, \quad (4)$$

$$a_{13} = \frac{r_{13}(r_{12} + r_{23})}{(E_{12} + E_{23})r_{13} + E_{13}(r_{12} + r_{23})}. \quad (5)$$

Approximating the experimental data on U_{13} at various R by the linear function (3), one can obtain coefficients b_{13} and a_{13}, hence

$$E_1 = 1/b_{13}\ ;\ r_1 = a_{13}E_1. \quad (6)$$

For a connection of the load resistor in parallel to the small electrode C_1 and the intermediate electrode C_2 , electromotive forces E_{13} and E_{23} are connected in series and are joined in parallel to the *e.m.f.* E_{12} (Fig. 2-



(2)).

Fig. 2. Second and third measurements

This means that the equivalent *e.m.f.* E_2 and the internal resistance r_2 corresponding to the second measurement (k=3, j=2) are

$$E_2 = \frac{(E_{13} - E_{23})r_{12} + E_{12}(r_{13} + r_{23})}{r_{12} + r_{13} + r_{23}}, \tag{7}$$

$$r_2 = \frac{r_{12}(r_{13} + r_{23})}{r_{12} + r_{13} + r_{23}}, \tag{8}$$

with coefficients

$$b_{12} = \frac{(r_{12} + r_{13} + r_{23})}{(E_{13} - E_{23})r_{12} + E_{12}(r_{13} + r_{23})}, \tag{9}$$

$$a_{12} = \frac{r_{12}(r_{13} + r_{23})}{(E_{13} - E_{23})r_{12} + E_{12}(r_{13} + r_{23})}, \tag{10}$$

of a linear regression

$$\frac{1}{U_{12}} = b_{12} + a_{12}\frac{1}{R}, \tag{10}$$

so that

$$E_2 = 1/b_{12}\ ;\ r_2 = a_{12}E_2. \tag{11}$$

Analogous expressions for the equivalent electromotive force E_3 and the internal resistance r_3 corresponding the third measurement (k=2, j=3) can be obtained from (7)-(11) by the replacements $r_{12}\to r_{23}$, $r_{13}\to r_{12}$, $r_{23}\to r_{13}$, $E_{12}\to E_{23}$, $E_{13}\to -E_{12}$, $E_{23}\to -E_{13}$ (Fig. 2-(3)). Thus

$$E_3 = \frac{(E_{13} - E_{12})r_{23} + E_{23}(r_{12} + r_{13})}{r_{12} + r_{13} + r_{23}}, \tag{12}$$

$$r_3 = \frac{r_{23}(r_{12} + r_{13})}{r_{12} + r_{13} + r_{23}}, \tag{13}$$

$$\frac{1}{U_{23}} = b_{23} + a_{23}\frac{1}{R}, \tag{14}$$

$$b_{23} = \frac{r_{12} + r_{13} + r_{23}}{(E_{13} - E_{12})r_{23} + E_{23}(r_{12} + r_{13})}, \tag{15}$$

$$a_{23} = \frac{r_{23}(r_{12}+r_{23})}{(E_{13}-E_{12})r_{23}+E_{23}(r_{12}+r_{13})}, \tag{16}$$

and, of course

$$E_2 = 1/b_{12}\ ;\ r_2 = a_{12}E_2. \tag{17}$$

All that mentioned above relates to usual conductors. For the electric current in liquid, it must be tested and confirmed. Especially it concerns to the net electromotive force as a superposition of E_{kj} created by various pairs of electrodes. Fig. 3 demonstrates results of measuring the load resistance dependencies of the voltages U_{kj} for all three variants of connections considered above. These simple and long in time measurements were curried out for c_1=1 cm, c_3=15 cm and for various values of radius of the intermediate electrode c_2 but at constant temperature 20^{O}C. For other values of c_2, the load resistance dependences are not much different shown in Fig. 3.

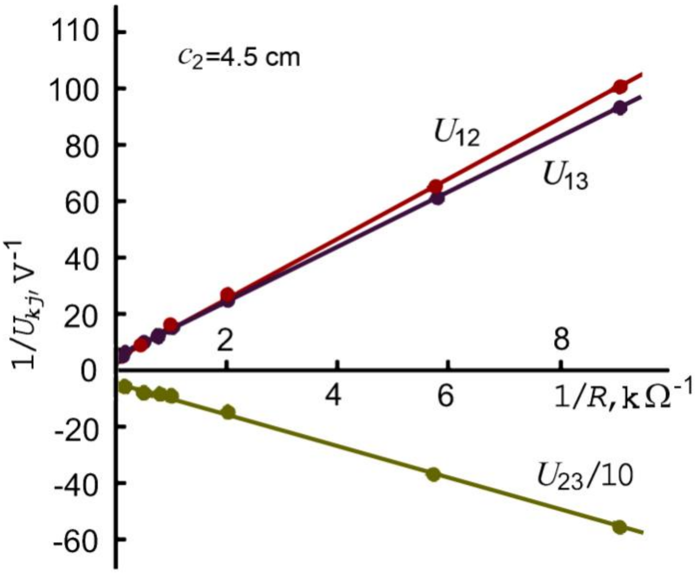


Fig. 3. Linearity of the inverse voltage versus conductivity of load resistor

First of all, representation of the voltage U as a dependence U=ER/(r+R) is correct with high accuracy. Secondly, consideration of the net *e.m.f.* as a superposition of electromotive forces E_k (k=1,2,3) which was made by necessity in order to determine E_{kj} and r_{kj}, is not superfluous. Although the dependences are near, the differences between them are essential.

III. EMF and internal resistances

Now we are in a position to solve the system of equations (2),(8),(13) that enables to obtain the internal resistances r_{kj} for measured values r_k from (6),(11),(17) :

$$r_{12} = -\frac{(r_1-r_2+r_3)^2-4r_1r_3}{2(r_1-r_2+r_3)}, \tag{18}$$

$$r_{13} = \frac{(r_1-r_2+r_3)^2-4r_1r_3}{2(r_1-r_2-r_3)}, \tag{19}$$

$$r_{23} = \frac{(r_1-r_2+r_3)^2-4r_1r_3}{2(r_1+r_2-r_3)}. \tag{20}$$

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For the obtained values r_{12}, r_{13}, r_{23}, and measured E_1,E_2, E_3, one can calculate the electromotive forces E_{12}, E_{13}, E_{23} by means of solving the system of equations (1),(7),(12):

$$E_{12} = \frac{(r_{12} + r_{13} + r_{23})[E_2(r_{12} + r_{23}) + (E_3 - E_1)r_{12}]}{r_{13}(r_{13} + r_{23})}, \tag{21}$$

$$E_{13} = \frac{(r_{12} + r_{13} + r_{23})E_1 - E_2(r_{12} + r_{13}) - E_3 r_{12}}{r_{13} + r_{23}}, \tag{22}$$

$$E_{23} = \frac{(r_{12} + r_{13} + r_{23})(E_2 - E_1)r_{23} + E_3[(r_{12} + r_{13})^2 + r_{12}r_{23}]}{r_{13}(r_{13} + r_{23})}. \tag{23}$$

In fact, this is a solution of the so-called ill-posed problem: unknown values of the electromotive forces are restrored from experimental dependencies U_k=$E_kR/(r_r+R)$. Results of the prosessing experimental data measured for five radii of the intermediate electrodes is found to be quite unexpected (Fig. 4). In general the electromotive force arizes in the range between first and second electrodes but there exists optimal radius of the second electrode at which the *e.m.f.* is maximal. Although the *e.m.f.* E_{12} is a hidden electromotive force, one should think how to extract the E_{12} exceeded at list two times one without second electrode [4].

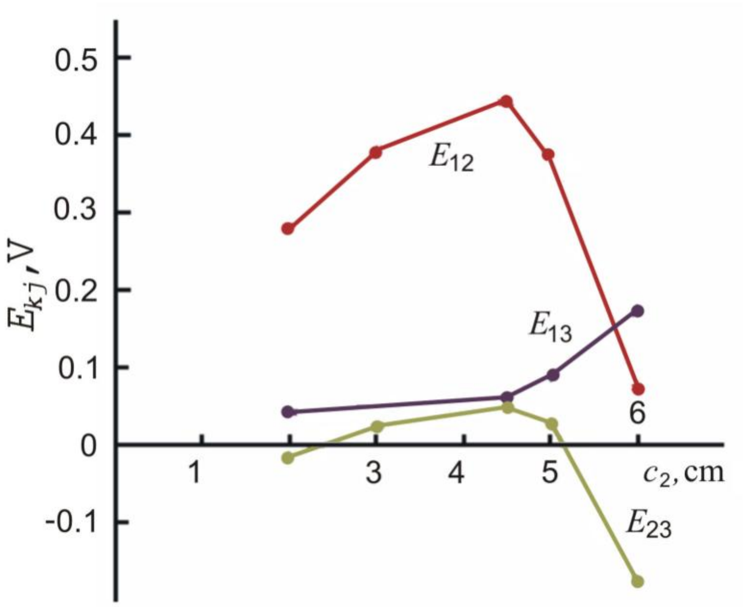

Fig. 4. Variations of electromotive force with radius of second electrode

Large magnitude of E_{12} says little about. Maximum of dissipated energy corresponds to the load resistance equal to internal resistance of a source of electric energy. Therefore one should pay attention to dependences of dissipated power P_{kj} on sizes of the system. In this case the power of electric energy developed in the load resistance R=r_{kj} is P_{kj}=$E_{kj}^2/4r_{kj}$.

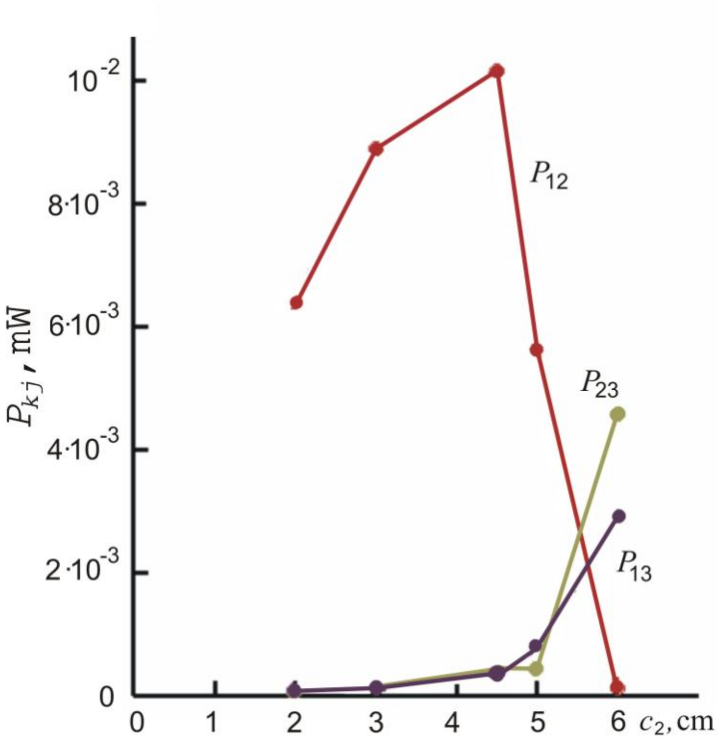

Fig. 5. Energy parameters of dark electric current

As in previous case, the dissipated energy is maximal at $c_2 \approx 4$ cm (Fig. 5). Of course it relates to the geometrical parameters of the system shown in Fig. 1. When the radius c_2 coincides with c_3, the total dissipated energy does not equal zero since power is additive value.

That's all for now what can be said about such a three-electrode still weak source of electric current.

IV. Conclusion

Apparently, an origin of the dark current is heat transfer from surroundings to the liquid not violating the second law of thermodynamics.

Sometimes one needs to spoil something to know what inside. Spoilage failed. Adding the third electrode into distilled water with two aluminum immersed electrodes, one can know what creates the electromotive force and choose parameters at which the produced energy is maximal.

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