Gravity-induced emf in superionic conductor $RbAg_4I_5$

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The electric field arising due to redistribution of mobile Ag^+ cations under the action of gravity is observed experimentally in the superionic conductor $RbAg_4I_5$. It is shown that under the experimental conditions the action of gravity on mobile cations is equivalent to the action of an emf.

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Superionic conductors or solid electrolytes form a new class of objects in solid state physics, combining the properties of crystals, amorphous bodies, and liquids. The variety of superionic conductors and methods for studying them is reflected, for example, in Ref. 1. A common property of this group of substances is the presence of an anomalously high ionic conductivity in the solid state, corresponding in order of magnitude to the conductivity of the melt. In addition, in a number of superionic conductors, the ionic conductivity exceeds the electronic conductivity by many orders of magnitude. It is also significant that in contrast to melts or electrolytic solutions, in a specific superionic conductor, a definite type of ion is responsible for the ionic conductivity; in cases where electronic conductivity can be ignored, it may be assumed that the conductivity of superionic conductors is strictly monopolar.

We can expect on the basis of the very general considerations presented above concerning the properties of superionic conductors that the existence of current carriers in such conductors with inertial and gravitational mass, exceeding by four to five orders of magnitude the mass of an electron, must lead to appreciable effects in a gravitational field or in other noninertial coordinate systems. Thus, for example, in a specimen placed in the earth's gravitational field, the charge carriers must be redistributed so as to compensate for the action of gravity on the mobile charges. The magnitude of the electric field arising in this case in the bulk of the specimen **E** is determined from the condition of equilibrium for an arbitrary ionic charge carrier.

$$M_i \mathbf{g} = \mathbf{E} e \,, \qquad (1)$$

where M_i is the mass of the ion responsible for the conductivity, g is the accelertion of gravity, and e is the charge of the ion. An electric field will arise in the specimen due to the different charge density at its upper and lower surfaces. The constancy of the concentration of mobile ions in the volume follows from the uniformity of g and the resulting uniformity of E in the volume of the specimen. Charge separation and transport against an electric field will occur due to the potential energy of atoms in near-surface layers of the upper boundary of the specimen or atoms in the materials of the upper contact, if the ions of the contact material can transport current in the specific superionic material. Thus the action of gravity on a monopolar conductor is equivalent to the action of some emf. In this case, the magnitude of the gravitational emf depends only on the charge-to-mass ratio for conduction ions and on the magnitude of the projection of the distance between contacts along the vertical. The magnitude of the ionic conductivity will determine the internal resistance of the source of the gravitational emf, while the mass of the material of the upper electrode will determine its energy content.

It should be noted that similar phenomena are known and were observed experimentally in other classes of objects. Thus, for example, a gravitational emf is realized experimentally in electrochemical cells of a special type[2]; experiments by Tolman and his colleagues on observation of the inertial emf in metals serve as proof of the electronic nature of the electrical current in metals.[3] In essence, superionic conductors with high ionic conductivity are merely a very convenient object for observing a general phenomenon: an emf due to noninertial forces.

For the experiments, we chose $RbAg_4I_5$, which has the highest ionic room-temperature conductivity of known ionic conductors (of the order of $0.25\ \Omega^{-1}\ \mathrm{cm}^{-1}$), due to the heavy mobile Ag^+ ions. The electronic conductivity of rubidium silver pentaiodide is negligibly small. Substituting numerical values into (1), we obtain for the magnitude of the electric field in $RbAg_4I_5$ in the earth's gravitational field $E = 1.05 \times 10^{-5}$ V/m, which corresponds to an emf of the order of a millivolt for a specimen of length 10 cm. It follows from this estimate that it is difficult to observe this effect in single crystals, since their linear dimensions do not exceed a centimeter. For this reason, we used 1-farad, 6.3-V series capacitors or "ionostores"[4] containing as specimens a crystalline solid electrolyte between the flat electrodes, one of which is a silver electrode. This permitted using sufficiently long specimens with low internal resistance, including the resistance of the region of contact with the solid electrolyte. The residual voltage on the ionostores, exceedings the expected effect by several orders of magnitude, presented a difficulty for the experiment. For this reason, after several discharge-charging cycles, four ionostores were connected in series counter-pairwise (see Fig. 1), so that the gravity-induced emf of separate ionostores was summed, while the residual voltages were subtracted. The battery was then short-circuited prior to making measurements for a time of the order of several days. The measuring procedure consisted of measuring the voltages on the ionostore battery prepared in this manner with differ-

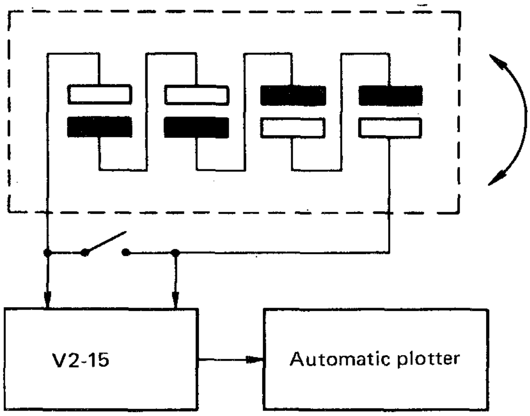

FIG. 1. Pivoted ionostore battery and measuring circuit.

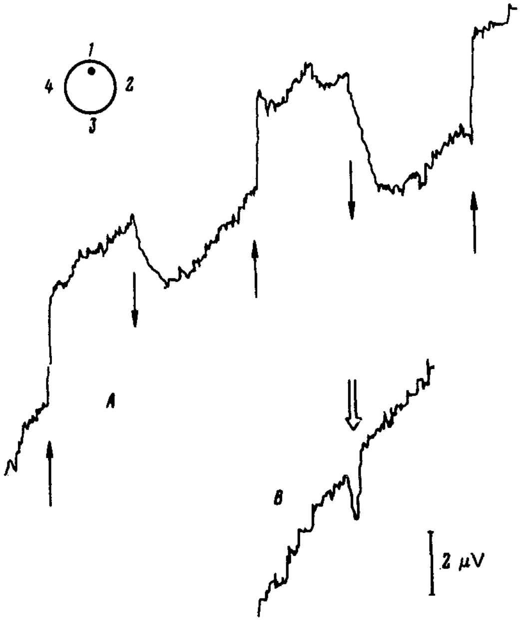

FIG. 2. Change in voltage of the ionostore battery accompanying reorientation of the battery. Curve A—Rotation 1-3-1-3-1; curve B—rotation 2-3-4. The times corresponding to the rotations are indicated on the curves by the arrows. The vertical scale of the curves is indicated in the lower right-hand corner.

ent orientations of ionostores relative to the vertical. The voltage was measured with a V2-15 microvoltmeter with a scale sensitivity of 100 μV and was recorded by an automatic plotter. This method for making the measurements turned out, in our case, to be better than the traditional method of compensating for the residual voltage, since the compensation current recharged the ionostores and the voltage on them constantly changed.

As a result, a difference was recorded in the experiment between the voltage of the ionostore battery with the ionostores oriented up and down $\Delta V \cong 3\ \mu$V (see Fig. 2). An estimate using Eq. (1) for the ionostore battery used gives the expected magnitude of the effect 1.1–4 μV. The large uncertainty in the estimate is related to the fact that it is impossible to estimate accurately the height of the electrolyte column in ionostores due to the presence of a transition region at the electrodes.

It should be noted that the experimentally recorded pressure in principle can be attributed to inhomogeneous deformation of the solid electrolyte ("squeezing out" of conduction ions from the region in which the crystal lattice is compressed).$^{1)}$ However, it can easily be shown that if the observed emf originates in this manner, then its sign must be opposite to the observed sign. In addition, in the ionostores, the solid electrolyte is pressed into plastic in a hermetically sealed metallic housing, which minimized the possibility of the appearance of deformations in the experiment.

The correspondence between the sign of the voltage observed in the experiment and the descent of cations in the gravitational field and the good agreement of the magnitude of this voltage with the theoretical estimate suggest that a gravity-induced emf was observed in the experiment.

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[1)] The model explaining the appearance of voltage accompanying inhomogeneous deformation of superionic conductors is due to Yu. M. Gerbshtein.

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[1] H. U. Baylor, J. B. Boys, P. Bruesh, *et al.*, Physics of Superionic Conductors [Russian translation. Ed. by M. B. Salamon, Zinatne, Riga, 1982].
[2] B. B. Damaskin and O. A. Petrii, Osnovy teoreticheskoĭ élektrokhimii (Foundations of Theoretical Electrochemistry), Vysshaya shkola, Moscow 1978, p. 122.
[3] R. C. Tolman and T. D. Stewart, Phys. Rev. **9**, 164 (1917).
[4] V. V. Treier, Zarubezhnaýa radioélektronika, No. 6, 124 (1977).

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