THERMO E.M.F. PHENOMENA IN CONTINUOUS ELECTRICALLY CONDUCTING BODIES AND PREDICTION OF EARTHQUAKES

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Introduction. A series of investigations implemented at the Institute of Physics UL, concerned with thermoelectric phenomena in different metals and alloys [1], has revealed the following: deformations and tensions, as well as any structurally inhomogeneous zone, in continuous bodies in the presence of temperature gradients give rise to thermoelectric currents. Being closed on themselves, the thermoelectric currents can be measured by measuring the magnetic field generated by these currents around the body.

It is known that seismic electric signals precede earthquakes [2]. Alike in seismically active regions, some change of the magnetic field has been registered in some cases prior to earthquakes. The report shows that the cause of these changes could be thermoelectric phenomena in the earth's crust when it is deformed by tectonic tensions [1].

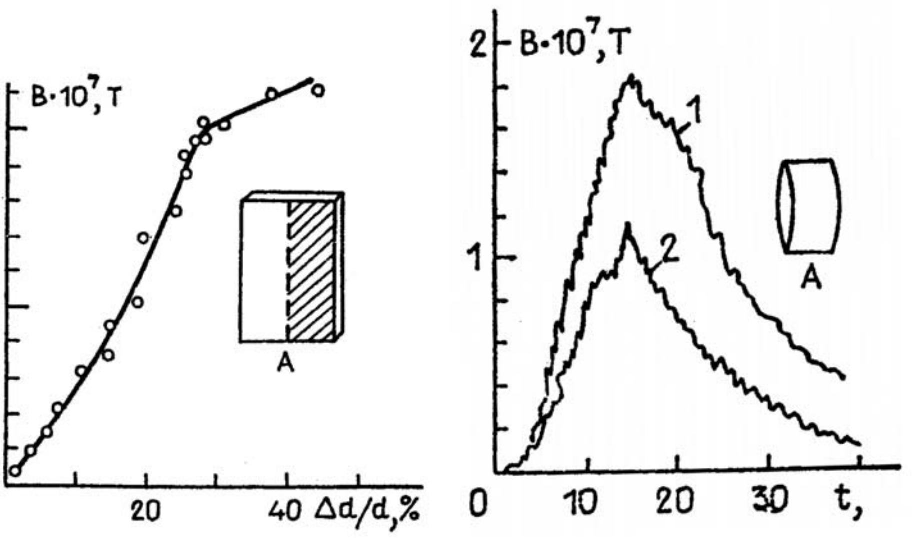
1. Presentation of the problem. Our experiments with cooled massive bodies showed that the magnetic field produced in their vicinity depends significantly on the degree of inhomogeneity of the body. The inhomogeneity may be chemical or phasic and may arise during phase transitions, or may be due to deformation of the material.

Fig. 1*a* shows a plot of the induction of the induced magnetic field against the degree of deformation near a copper plate heated to 400°C and then face A was immersed in flowing water. The copper was 5 × 7 × 0.3 cm. Before each measurement one half of the plate (hatched half, Fig. 1*a*) was deformed by compression. The points on the curve correspond to different values of the degree of deformation $\Delta d/d$. The magnetic field was measured with a thermostated ferroprobe transducer at the center of the plate and 2 cm from its surface. The results of the measurements were recorded.

Since the temperature field in the plate varied continuously during cooling, the recorder traced a curve with a distinct maximum. The points on the curve in Fig. 1 correspond to the maximum values of the induction recorder by the instrument at different $\Delta d/d$.

Fig. 1*b* shows the results of measurements of the magnetic induction near rapidly cooling graphite (curve 1) and corundum (curve 2) cylinders. Surface A of the cylinders, which were heated to 500°C, was immersed to a depth of 1 cm in flowing water. The radial component of the induction was measured at a distance of 2 cm from the center of the end face. An estimate of the mean density of the thermoelectric current in the graphite cylinder gave a value of about 160 mA/cm^2.

We also shall turn attention to the numerical simulation on time changes of metal mechanical state a short time after conclusion of solidification process [3]. Numerical experiments were implemented for bismuth solidification, these results show that one of the physical reasons of the thermoelectric currents origin may be a rapid transition of the metal mechanical state (for example, from plastic to elastic).



(*a*) (*b*)

Fig. 1. (*a*) Maximum induction at a 2 cm distance from the center of a cooled copper plate as a function of relative deformation of the hatched region. (*b*) Change in magnetic field at a 2 cm distance from a cylinder cooled down from 500°C; 1) graphite cylinder; 2) corundum cylinder.

In the earth's mantle the temperature gradient is produced by a natural temperature distribution. In seismically active regions and at epicenters of earthquakes tectonic tensions can lead to considerable changes in the electrical conductivity, the thermoelectromotive force, and the magnetic susceptibility of the rocks. Depending on the density of the current produced and the orientation of the loops the induced magnetic field will reduce or increase the earth's magnetic field to some extent.

For a comparative assessment of the expected effect, we carry out some quantitative calculations. A gradient temperature distribution in any conductor with an inhomogeneous composition gives rise to a thermoelectric current with a density

$$j = -\sigma \Delta\alpha \, \mathrm{grad}\, T \,, \tag{1}$$

where σ and α are the electrical conductivity and thermo e.m.f.; Eq. (1) corresponds to the case when extraneous electromotive forces are absent. For nonmetallic materials of fireclay or pyrite type (it is assumed that $\Delta\alpha = 100\ \mu$V/K, $\sigma = 40$ S/m) with gradient 5 K/km we have

$$j = 20.0 \cdot 10^{-6}\ \mathrm{A/m^2} = 20.0\ \mathrm{A/km^2}.$$

Furtheron we will find how the magnetic field will be distorted by thermoelectric currents. We assume that tectonic tensions in the earth's crust give rise to a closed loop of thermoelectric current in the form of a square with sides $2a = 2b = 20$ km. The cross-section of the current loop is also square with a side $l = 2$ km. This corresponds physically to a plate with dimensions $22 \times 22 \times 2$ km, one vertical side of which is deformed by tectonic forces.

To calculate the magnetic field of such a loop, we use the Biot–Savart's law [4]

$$B_x = -\frac{\mu_0 I}{4\pi l}\left\{\left[\left(\operatorname{arcsinh}\frac{\beta}{\sqrt{\alpha^2+\eta^2}}\right)_{\alpha_1=x+b}^{\alpha_2=x-b}\right]_{\beta_1=y+a}^{\beta_2=y-a}\right\}_{\eta_1==l+z}^{\eta_2=l-z}; \qquad (2)$$

$$B_y = -\frac{\mu_0 I}{4\pi l}\left\{\left[\left(\operatorname{arcsinh}\frac{\beta}{\sqrt{\beta^2+\eta^2}}\right)_{\alpha_1=x+b}^{\alpha_2=x-b}\right]_{\beta_1=y+a}^{\beta_2=y-a}\right\}_{\eta_1==l+z}^{\eta_2=l-z}; \qquad (3)$$

$$B_z = -\frac{\mu_0 I}{4\pi l}\left\{\left[\left(\operatorname{arccot}\frac{\alpha\beta}{\eta\sqrt{\alpha^2+\beta^2+\eta^2}}\right)_{\alpha_1=x+b}^{\alpha_2=x-b}\right]_{\beta_1=y+a}^{\beta_2=y-a}\right\}_{\eta_1==l+z}^{\eta_2=l-z}. \qquad (4)$$

In expressions (2)–(4) the z-axis is vertical, the y-axis is perpendicular to the plane of the loop, and the x-axis is parallel to the plane of the loop. The coordinates of the center of the loop are (0, 0.5 l, 0).

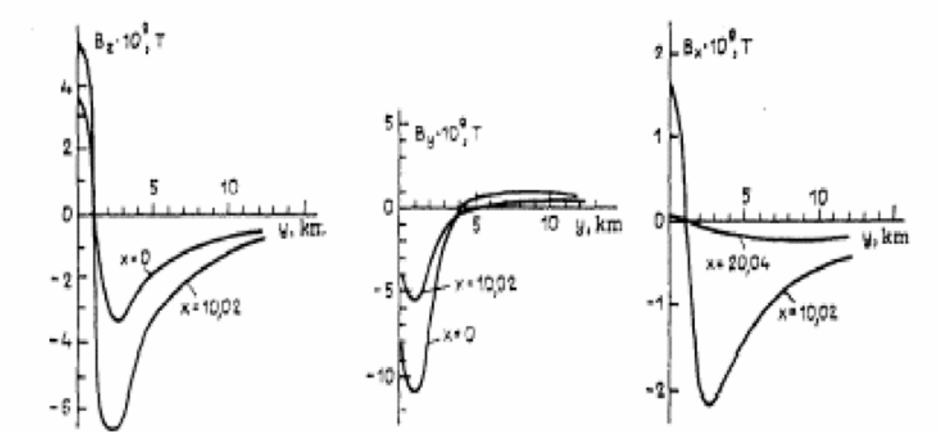
We obtain the current I from the above estimates for the thermoelectric current density. We have

$$I = jS = 20.0\ (\mathrm{A/km^2}) \cdot 4\ \mathrm{km^2} = 80.0\ \mathrm{A}\,.$$

Fig. 2 show the distribution curves, calculated from formulas (2)–(4), for the induction components of the magnetic field caused by the thermoelectric currents on the earth's surface ($z = 11$ km).

It is apparent that the y-component of the magnetic field has a maximum value at $x = 0$, i.e., above the center of the loop at a distance $b = 10$ km from the deformed zone (edge of the plate). The epicenter is situated on the line of maximum change of the y-component and zero change of the z and x components.

We must stipulate here that all we said can be attributed to the case, where the thermoelectric current is replaced by a single square current loop. In the real situation both the shape and the number of loops can be arbitrary and will depend on the electric conductivity of the material of the earth's crust in the epicenter region – the source of the thermoelectric currents.



(a) (b) (c)

Fig. 2. (*a*) Vertical component B_z of the magnetic field produced by thermoelectric currents as a function of distance from the center of a hypothetical loop. (*b*) Horizontal component B_y of the magnetic field as a function of distance from the center of a hypothetical loop. (*c*) Horizontal component B_x of the magnetic field as a function of distance from the center of a hypothetical loop.

It is apparent that the change in induction is a few units of 10^{-9} T, i.e., corresponds to the variations observed during earthquakes [5].

Proceeding from the hypothesis of the thermoelectromagnetic nature of the changes in magnetic induction, we can attempt an explanation of the results of magnetic measurements in the period preceding some earthquakes . It is possible that in the Alai earthquake of 1978 [6] the increase in variation of the magnetic induction ΔB (difference in inductions between Andizhan and Tashkent) corresponded to the increase in tensions in Andizhan region, and the reduction of the variation immediately before the earthquake probably indicates the removal or redistribution of tensions.

It should be noted that induction changes due to the thermoelectric effect can be expected in regions of active volcanoes.

2. Conclusion. A comparison of synchronous measurements of the magnetic field at geomagnetic observation points situated in seismically active regions and regions adjacent to them (together with other prognostic methods) may be promising in order to determine the time and the location of an imminent earthquake. The magnetic field generated by thermoelectric currents is very non-regular (Fig. 3, 4, 5), therefore, it is important to measure all three components B_x, B_y, B_z together at several points.

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