ON THE EXISTENCE OF A LINEAR RELATION BETWEEN ∇T AND $\partial H/\partial t$ IN ANTI-FERROMAGNETS

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An attempt is made to observe experimentally a linear relation between the magnetic field and the temperature gradient in an antiferromagnetic material whose magnetic structure permits a magnetoelectric effect. The possibility of the existence of the effect investigated has been predicted theoretically [5], but within the limits of sensitivity of the method used, the result was negative.

IT is well known that in certain antiferromagnetic materials it is possible to observe peculiar effects involving a linear relation between the mechanical stress applied to the crystal and the magnetic moment (piezomagnetism) [1], and also between an applied electric field and the magnetic moment (magnetoelectric effect) [2,3]. The existence of these effects is due to peculiarities of the magnetic symmetry of the corresponding crystals.

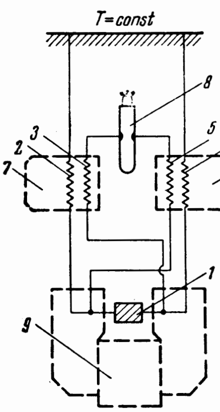
In particular, in order that a magnetoelectric effect should exist it is necessary that terms proportional to the product of components of the polar vector **E** and the axial vector **H** should be preserved in the thermodynamic potential of the crystal in all symmetry transformations.

The existence of such a relation for a crystal of chromic oxide, Cr_2O_3, was predicted on the basis of thermodynamic theory [4] and was then observed and studied experimentally. Along with this it is easy to see that according to the same considerations, in a crystal with the magnetic symmetry of Cr_2O_3 there should exist such a linear relation between any two quantities, one of which is described by a polar and the other by an axial vector.

Turov and Shavrov [5] suggested the possibility of the existence of a linear relation between the magnetic field and the gradient of the temperature. However, effects connected with the presence of a nonvanishing temperature gradient in the crystal can be described only in a kinetic theory, and a derivation of the appropriate formulas within ordinary thermodynamic theory is in general impossible. Thus the analogy with thermodynamic theory used by Turov and Shavrov is only in the nature of a suggestion. If we use the principle of symmetry of the kinetic coefficients, then in general it is possible, by adjusting the heat current to zero, to obtain the desired linear relation between ∇T and the derivative of the magnetic field with respect to time, $\partial H/\partial t$. Since in the equation for the heat current the terms containing ∇T and $\partial H/\partial t$ are on a par, the existence both of a direct effect—production of ∇T by application of a variable field H—and of an inverse seemed possible. We remark that in thermodynamic theory, this question in general would not arise. With existence of a direct effect, the existence of the inverse is not subject to doubt. It is clear that the coefficient of proportionality between ∇T and $\partial H/\partial t$, which determines the size of the expected effect, can be estimated only on the basis of a model. Even for a relatively simple phenomenon—the magnetoelectric effect—it has until now not been made sufficiently clear whether the effect is determined by exchange forces or by spin-orbit coupling.

More than that, there has been no success in pointing out any possible mechanism that leads to the occurrence of ∇T in a uniform magnetic field, which in general does not interact directly either with the acoustic or with the optical dipole oscillations of the phonon spectrum of the crystal. As regards the influence of magnetoelastic coupling, a constant magnetic field, as is known, can lead in a ferromagnet only to a change of the energy of available excitations, for example to a change of the speed of propagation of acoustic waves [6], but not to the origination of any phonon currents. According to these considerations, the very possibility of existence of the effect predicted in [5] appears very doubtful.

In view of the insufficient clarity of the question, we made an attempt to observe the expected effect experimentally. We chose the method of application of an alternating magnetic field and measure-



ment of the expected difference of temperature (flow of heat) in the specimen. This choice was determined by the possibility of obtaining an extremely large sensitivity.

The essential scheme of the experimental setup is shown in the figure. The monocrystalline specimen of chromic oxide, 1, was placed in an alternating magnetic field of intensity about 1.5 kOe, produced by the electromagnet 9. Thermal contacts to the specimen were insured by melting-in silver paste. To the specimen were attached, on each side, a pair of heat conductors; the value of their thermal resistivity could be greatly changed by means of the superconducting switches 2 to 5, controlled by a magnetic field from the two sources 6 and 7. Two of these heat conductors (2 and 4) connected the specimen to a body of constant temperature; the other two (3 and 5) connected it to the temperature-change indicator 8, a germanium resistance thermometer [7]. The phase of the magnetic field controlling the switches, relative to the field of the basic electromagnet, could be so selected that the expected heat current passed from the germanium thermometer for both directions of the alternating magnetic field. The system should act like a two-cycle heat pump. The whole apparatus was placed in a high vacuum, produced by a carbon sorption pump. The operating frequency was chosen low enough to exclude the influence of temperature waves in the specimen and the heat conductors; it lay in the range 3 to 25 cps.

The result of the experiment was negative. For all possible phases of the magnetic field controlling the switches relative to the field of the basic electromagnet, corresponding both to an expected cooling and to an expected heating, we observed no reproducible change of temperature according to the indications of the germanium thermometer. Similar results were also obtained with use of the oxide of titanium, Ti_2O_3, whose magnetic structure according to our measurements coincides with the structure of Cr_2O_3 [8], but whose heat conductivity is much larger.

According to our estimate, we could observe the expected effect if the magnitude of the coefficient of proportionality between ∇T and $\partial H/\partial t$ were not smaller than 10^{-6}.

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