HALL EFFECT IN A FERRIMAGNET WITH A COMPENSATION POINT

I. EXPERIMENTS ON Mn_5Ge_2

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The Hall effect was investigated near the compensation point. It is shown that the Hall emf and the anomalous Hall coefficient change their sign at this point. To explain this, it is suggested that the Hall potential difference includes a component which is an odd function of the antiferromagnetic vector.

IN connection with the study of the galvanomagnetic properties of uncompensated antiferromagnets, the question arose whether these properties are governed only by the resultant spontaneous magnetization M_s or whether they depend also on the antiferromagnetic vector **L**, i.e., on the magnetic sublattice structure. Valuable information on this point can be obtained by investigating ferromagnets with a compensation point since in them, due to the presence of spontaneous magnetization, we can orient **L** in any desired way. The problem of the dependence of the electrical properties on **L** was analyzed theoretically in the work of Turov and Shavrov,[1,2] who showed that several galvanomagnetic effects governed by the vector **L** may exist in uncompensated antiferromagnets. One of them was detected by us in Mn_5Ge_2 near its compensation point.[3]

In the present paper, we report the results of an investigation of the Hall effect in the same compound. A sample was prepared using a method described earlier.[4] The Hall emf was measured with a low-resistance potentiometer and a galvanometer with a sensitivity of 2×10^{-8} V/division. To eliminate secondary effects, the measurements were carried out for two directions of the magnetic field and two directions of the current in the sample. To measure the magnetization, the sample was placed in a pendulum balance of the Dominicali type and oriented with respect to the magnetic field in exactly the same way as in measurements of the Hall effect.

The temperature dependence of the Hall emf E_H in a field of 16,000 Oe is shown in the figure. Near the compensation point Θ_c the value of E_H changes its sign. The dependence of the Hall potential difference on the magnetic field intensity is the same as for all ferromagnets and, therefore, we can write

$$E_H = (R_0 H + R_f M) I / d, \tag{1}$$

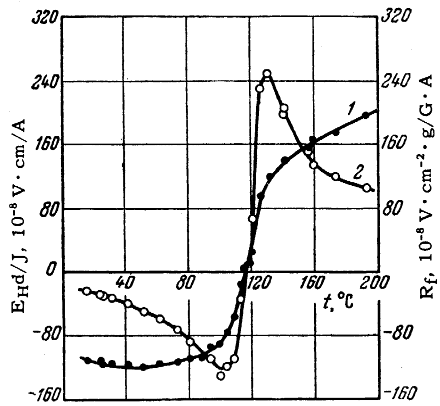
where R_0 is the normal Hall coefficient, R_f is the anomalous Hall coefficient, H is the magnetic field intensity, M is the technical magnetization of the sample, I is the current in the sample, and d is the sample thickness.

In this case, it is necessary to calculate two constants from the experimental data. However, it was not possible to reach saturation in our sample in the available fields up to 16,000 Oe and, consequently, we could not determine R_0. It is known, however, that, as a rule, $R_0 \ll R_f$ and therefore we find approximately that

$$E_X \approx R_f M I / d. \tag{2}$$

The error arising in this approximation can be estimated for our substance using the Hall emf values near the compensation point where $R_f M$ is close to zero. A calculation shows that $R_0 H$ amounts to 2–3% of the total emf. Only for temperatures in the immediate vicinity of the compensation point does the error amount to 20–30%. Consequently, the dependence of E_H on M, plotted from the experimental data, represents a straight line.

The large value of the anomalous Hall coefficient is a notable feature of the results calculated in this way. For Mn_5Ge_2, $R_f = -118 \times 10^{-8}$ V-cm^{-2} g/G.A at a temperature $T/\Theta = 0.46$, and for nickel at the same temperature, $R_f = 5.3 \times 10^{-10}$ V-cm^{-2} g/G.A.[5] Such a very large Hall coefficient has been reported for metals only in the case of chromium telluride[5]. It is possible that this is related to the high electrical resistivity of Mn_5Ge_2: at 20°C, $\rho = 10^{-4}$ Ω-cm.



Temperature dependence of the Hall emf in a field of 16 000 Oe (1) and of the Hall coefficient (2).

The dependence of R_f on temperature is shown in the figure. Examination of this figure reveals that the dependence is quite complex: near the compensation point the Hall coefficient reaches maximum absolute values, and in a narrow range of temperatures, in the immediate vicinity of Θ_c, the coefficient R_f changes its sign.

In order to find whether the change of sign of the Hall coefficient is related to a change of the type of conduction, we determined the sign of the thermoelectric power with respect to lead[1)] above and below the point Θ_c. It was found that this sign did not change on transition through the compensation point, thereby indicating that no change in the type of conduction took place.

We can explain the observed dependence $R_f = R_f(T)$ by assuming that the coefficient R_f, found from Eq. (2), is an odd function of the antiferromagnetic vector **L**. Since the Hall emf is measured in a magnetic field, the directions of the vector **L** are opposite above and below the compensation point because the resultant magnetization is directed along the magnetic field. This gives rise to the reversal of the sign of the anomalous Hall coefficient at the compensation point.

The relationship between the Hall potential difference and the antiferromagnetic vector is validated in the phenomenological theory of Turov and Shavrov[1,2,6], who have shown that the Hall emf has a component proportional to **L**, as well as a component proportional to the magnetization.

It follows from the foregoing that the Hall emf measured in the absence of a magnetic field should not change its sign at the compensation point since then the vector **L** does not change its direction. To check this conclusion, we carried out qualitative measurements of the residual Hall emf E_r, obtained on application of a magnetic field at room temperature. Analysis of the results obtained showed that below and above Θ_c the value of E_r had the same sign.

[1)]Lead was taken as the second material because it has a very low thermoelectric power.

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[6] Turov, Shavrov, and Irkhin, JETP **47**, 296 (1964), this issue p. 198.

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