Observation of thermomagnetic waves in antimony

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In 1978, thermomagnetic waves were observed in bismuth. These electromagnetic waves propagate because of the carrier drift which appears as a result of transmission of heat flux through a sample. Our goal in this letter is to show that bismuth is not the only metal in which these waves can be observed.

We have chosen antimony as the object of our investigation. Antimony is a semimetal whose electronic properties resemble most closely those of bismuth. The antimony sample[1)] used by us was cylindrical in shape ($\phi \approx 1.2$ cm, $l \approx 12$ cm) and was comprised of several crystallites having different orientations. The resistivity ratio measured at room temperature and at helium temperature was $(3\text{-}4) \times 10^3$.

The method of observing the waves was essentially similar to that used by us elsewhere[1]: The heater, which produced a temperature gradient, was situated in the upper part of the sample and the relay coil, which was connected to the generator, was placed in the lower part of the sample. The signal of this pickup coil was amplified and transmitted to the synchronous detector whose output voltage was recorded as a function of frequency by an X-Y recorder.

The characteristic temperatures of the helium bath at which the experiment was carried out were 1.3-2 K. At these temperatures the superheating of the sample with respect to the bath was 1-2 K.

The experimental curves are shown in Fig. 1. We see that the signal is missing at a low power level of the heater, but an oscillating signal appears as the power is increased. The period, the amplitude, the number of oscillations and the upper frequency limit increase with increasing power. The transmission of the signal is linked with the propagation of thermomagnetic waves. The oscillating shape of the output signal of the synchronous detector is attributable to the sinusoidal shape of its phase characteristic. The number of oscillation periods corresponds to the number of waves piled up between the transmitting and receiving coils. A good frequency periodicity of the oscillations within the limits of each curve indicates that the wave dispersion is linear ($k \sim \omega$), and an increase of the oscillation period with increasing power corresponds to an increase of the phase velocity of the observed wave. We saw no evidence of signal propagation in the opposite direction to the heat flux.

All these effects can be explained in terms of the theory of thermomagnetic waves,[2] according to which the dispersion law is given by

$$\omega = -a_1 c \nabla T k - i \rho c^2 k^2 / 4\pi ,$$

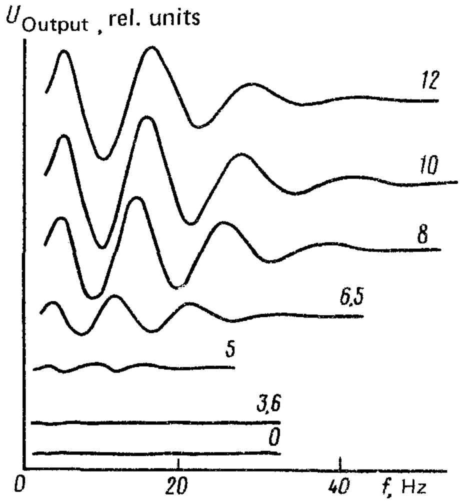

FIG. 1. Frequency dependence of the output signal of a synchronous detector for different values of the power produced by the heater. The numbers on the curves indicate the values in watts.

where α_1 is the Nernst-Ettingshausen coefficient, and ρ is the resistivity.

The characteristic frequencies (~ 50 Hz) and velocities (~ 50 cm/sec) of the waves observed in antimony at approximately the same heat flux turned out to be appreciably lower than in bismuth, consistent with the dispersion law and with the fact that the concentration of free carriers in antimony is much higher than in bismuth, since the phase velocity of waves is of the order of the drift velocity of the carriers.

Using a known value of thermal conductivity (~ 10 W/cm · K), we estimated the value of the Nernst-Ettingshausen coefficient from the experimental data; it turned out to be ~ 10^{-5} V/Oe · K, in agreement with the known data in the literature.[3]

These results show unambiguously the presence of thermomagnetic waves in antimony (whose concentration of free carriers is two orders of magnitude higher than in bismuth). This expands considerably the range of substances in which this new and, in our opinion, important effect can be observed.

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