THERMOELECTRIC POWER AND THERMOMAGNETIC EFFECTS IN GADOLINIUM AT LOW TEMPERATURES

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An investigation was made of the thermoelectric power and thermomagnetic effect in gadolinium as a function of the magnetic field intensity up to 38 kOe, at temperatures from 15 to 92°K. In agreement with the theory, a maximum of the thermoelectric power was found at low temperatures. The extremal values of the thermomagnetic saturation effect were obtained and the values of $d\Delta Q/dH$ were found in the range of temperatures at which the thermoelectric power maximum was observed.

THE thermoelectric power of gadolinium has been investigated by several workers[1,2] at temperatures from 70 to 300°K. However, no studies have yet been made of the most interesting temperature range (from 4.2 to 70°K), where a theoretically predicted maximum of the temperature dependence of the thermoelectric power should be found. The present paper describes the results obtained in a study of the thermoelectric power and thermomagnetic effect of gadolinium in the temperature range from 15 to 92°K.

DESCRIPTION OF THE APPARATUS

The thermoelectric power of gadolinium was measured using a potentiometric method. An FÉOU-18 amplifier was used because the change in the thermoelectric power in a magnetic field was small (up to 0.01 μV). Low-temperature measurements of the thermoelectric power were carried out in a special unit designed for the temperature range 15–100°K. A cylindrical sample (30 mm long and 3 mm in diameter) was placed in a holder. The ends of the sample were in contact with brass rods, which carried heaters. These heaters made it possible to obtain a stable temperature gradient of 2–6 deg across the sample. The temperature was measured with two copper-constantan thermocouples. The thermocouple emf was measured with an R-306 potentiometer and an M-21/4 galvanometer. The temperature gradient was measured with an accuracy of 0.1 deg. During the mounting of the sample special attention was paid to the thermal contact between the thermocouples and the sample. The potential probes used to measure the thermoelectric power were welded to the middle part of the sample, 10 mm apart, and the hot junctions of the thermocouples were also located in that part of the sample. All leads from the sample and thermocouples were enclosed in a Staybrite tube. The sample was placed in a double-walled glass tube. The space between the two walls was evacuated to 10^{-7} mm Hg. The glass tube was immersed in a Dewar flask with liquid helium. The use of the double tube and of heaters enclosed within the tube made it possible to maintain stable temperatures with a constant gradient along the sample by a combination of heating and variation of pressure of the heat-exchange helium within the glass tube. The temperature of the sample was assumed to be the average of the values of the readings of the first and second thermocouples. The magnetic field was established by a superconducting solenoid. The measurements were carried out in fields of up to 38 kOe. We investigated a sample of gadolinium prepared at the State Scientific-Research and Design Institute for the Rare-Metal Industry, Moscow (GIREDMET). According to the results of a chemical analysis, the sample contained the following impurities: no trace of Sm; no trace of Eu; 0.04% of Y; 0.02% Tb; < 0.01% Fe; < 0.01% Cu.

RESULTS OF THE INVESTIGATION

Figure 1 shows the temperature dependences of the thermoelectric power Q of gadolinium in the temperature range 15–92°K. The experimental dependence shows a thermoelectric power maximum in the region of 30°K. Figures 2 and 3 show the dependences of the thermomagnetic effect ΔQ on the magnetic field H at various temperatures. In the temperature range 15–40°K (Fig. 2), the value of the thermoelectric power increases with increasing field intensity, and in strong fields (in the magnetic saturation region) the dependence of the thermoelectric power on the magnetic field is linear. The nature of these dependences changes somewhat when the temperature is increased and parts of the curves corresponding to the technical magnetization (saturation) of gadolinium can be seen more clearly.

DISCUSSION OF THE RESULTS

The theoretical investigations of several workers[3-5] explain qualitatively the anomalous temperature dependence of the electrical resistivity and thermoelectric power in the ferromagnetic region. One of the authors of the present paper (P. A. M.) has calculated the contribution to the thermoelectric power associated with the scattering of electrons by magnons using a two-band model and has obtained a formula for the temperature dependence of this contribution at low temperatures. This formula, like the theory of Kasuya,[3] predicts a maximum in the temperature dependence of the thermoelectric power.

Figure 1 includes the theoretical temperature dependence of the thermoelectric power, obtained using

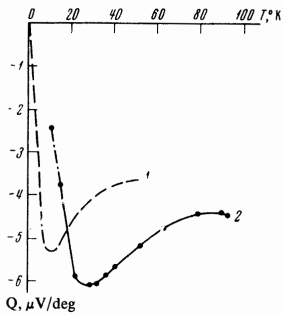

FIG. 1. Temperature dependences of the thermoelectric power Q of gadolinium: 1)theoretical; 2)experimental.

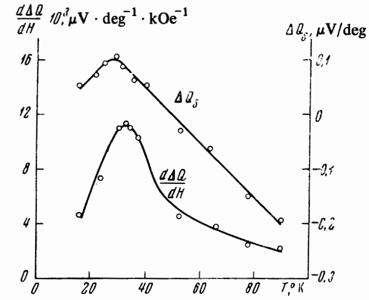

FIG. 4

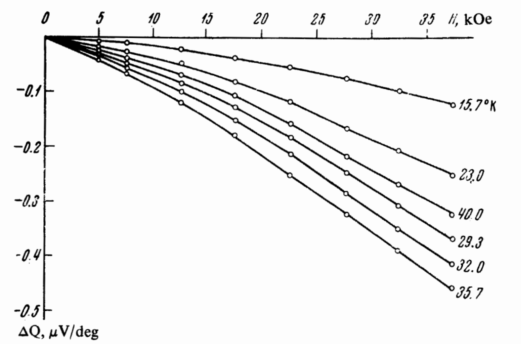

FIG. 2

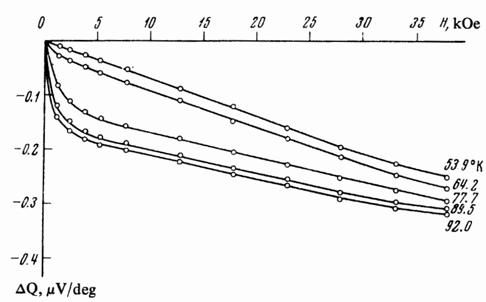

FIG. 3

Eq. (20) in [5], as well as the curve plotted using our experimental data for gadolinium. The parameters μ, v_s/v_d, G_{ss}, G_{sd}, required to plot the theoretical temperature dependence of the thermoelectric power of gadolinium, were selected in the same way as by Goodings:[4] μ = 5.6 eV; v_s/v_d = 8.8; G_{ss} = 0.07 eV; G_{sd} = 0.12 eV. We can see from Fig. 1 that the theoretical curve, plotted using these values of the parameters, passes close to the experimental curve and has the same nature. The appearance of the maximum in the temperature dependence of the thermoelectric power can be easily understood on the basis of the following physical considerations. The anomalous component of the thermoelectric power of ferromagnetic substances, which is associated with the existence of spontaneous magnetization and is larger than the "normal" component, decreases on approach to the Curie point. On the other hand, since this component is due to the scattering of electrons by magnons, its value also decreases when the temperature is reduced in the low-temperature range. The temperature at which a maximum is observed depends, as predicted by Eq. (20) in [5], on the exchange energy and the relative velocity of the band electrons. We must mention that the model used in [5] better represents the rare-earth ferromagnetic metals than the metals of the iron group.

The field dependences of the thermomagnetic effect (Figs. 2 and 3) have an initial region (the weak-field region) where the change in the thermoelectric power in a magnetic field is mainly due to the technical magnetization (saturation) process. According to Akulov's theory of the even effects,[6] the thermomagnetic effect should be proportional to I^2 in this range of fields. We calculated the dependence of the thermomagnetic effect ΔQ, recorded at 78° K, on I^2 (the values of the magnetization were taken from the magnetization curves). This dependence was linear within the limits of the experimental error). The parts of the curves (Figs. 2 and 3) lying in the strong magnetic field region correspond to the process of absolute (paraprocess) magnetization. The change in ΔQ in this region is due to an increase in the spontaneous magnetization with increasing magnetic field intensity.

Figure 4 shows the temperature dependence of $d\Delta Q/dH$ in the paraprocess region (H = 35 kOe). This temperature dependence has a maximum at 35°K. The same figure shows the temperature dependence of the saturation value of the thermomagnetic effect ΔQ_s. The value of ΔQ_s was obtained from curves in Figs. 2 and 3 by extrapolation of the linear part of the field dependence of the thermomagnetic effect so that it intersected the ordinate. ΔQ_s obtained in this way represents the saturation value of the thermomagnetic effect at a given temperature. The temperature dependence of the saturation value of the effect has a maximum at 29° K. The value of ΔQ_s changes its sign when the temperature is increased: between 15 and 50° K the values of ΔQ_s are positive; above 50° K they are negative. It is evident from Figs. 1 and 4 that the extremal values of $d\Delta Q/dH$, ΔQ_s, and thermoelectric power are observed in the same temperature range.

In conclusion, the authors thank A. I. Shal'nikov for his constant interest and help in this investigation.

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