INFLUENCE OF UNIFORM COMPRESSION ON THE CURIE TEMPERATURE OF THE FERROMAGNETIC COMPOUND EuO

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The dependence of the Curie temperature of the compound EuO under uniform compression was investigated at pressures up to 12 katm. It is shown that in this range of pressures the Curie temperature of EuO increases linearly with pressure: $d\Theta/dp = (4 \pm 1) \times 10^{-4}$ deg/atm.

A strong dependence of the magnitude and sign of the exchange interaction on the lattice parameter was discovered in an investigation of the magnetic properties of a group of divalent europium compounds, having the rock-salt structure, which included EuO, EuS, EuSe, and EuTe.[1,2] This dependence was deduced from the results of the measurements of the Curie temperature of these compounds. The separation between the europium atoms was varied by the introduction of various anions. When these compounds were arranged in increasing order of the anion radius, i.e., in increasing order of the lattice parameter, it was found that the Curie point gradually decreased in the transition from EuO to EuS and, further, to EuSe, while EuTe, which had the largest lattice parameter, was found to be an antiferromagnet with an asymptotic Curie point below 0°K. However, it should be mentioned that the magnitude of the exchange interaction may vary not only with the interatomic spacing but also with changes in the nature of the atomic environment.

For these reasons, it was interesting to investigate the shift of the Curie point under the action of uniform high pressure, when the lattice parameter was altered by a direct mechanical effect. We chose to investigate the oxide, EuO, which had the highest Curie point and the smallest lattice parameter in the aforementioned group of compounds.

To determine the ferromagnetic Curie temperature of europium oxide, we used the method described by Tul'chinskiĭ.[3] An irregularly-shaped sample was placed in one of two sections of a differential measuring coil. We measured the induced emf produced in this coil in a 5 kc magnetic field of about 50 Oe. The Curie temperature was determined from the sharp discontinuity in the induced emf when the sample was cooled.

The sample, together with its measuring and magnetizing coils, was placed in a high-pressure steel chamber. The method of applying quasihydrostatic high pressure at the temperature of liquid nitrogen was similar to that described by Itskevich.[4] A 50% solution of dehydrated transformer oil and kerosene was used as the pressure-transmitting medium. The pressure in the chamber at 77°K was determined using a manganin resistance manometer. As shown in [4], the dependence of the electrical resistance of a manganin manometer on pressure was practically linear in the investigated range of temperatures and pressures, and the pressure coefficient of manganin $R_0^{-1}\Delta R/\Delta p$, increased by 1% only in this range, which introduced a permissible error in the determination of the pressure. The maximum pressure reached was 12 katm.

The oxide EuO was synthesized (in cooperation with the Chemistry Institute of the Ural Branch of the U.S.S.R. Academy of Sciences) from Eu_2O_3 by the method of carbon reduction. X-ray diffraction investigations of the synthesized oxide showed a perfect crystal lattice of the NaCl type with the parameter $a = 5.142 \pm 0.002$ Å, which was very close to the published value.[5]

The temperature dependence of the induced emf V(T) was investigated at several fixed pressures. In the 80–60°K range, the temperature was varied by pumping nitrogen vapor from a Dewar containing liquid nitrogen, in which the high-pressure chamber was located. In all the experiments, the temperature was measured and kept constant to within ± 0.1 deg C. A series of V(T) curves for several values of pressure is shown in Fig. 1.

The Curie point was determined as the point of intersection of the tangents to the sharply descending parts of the V(T) curves with the lines to which all these curves tended in the paramagnetic region. According to our data, the Curie

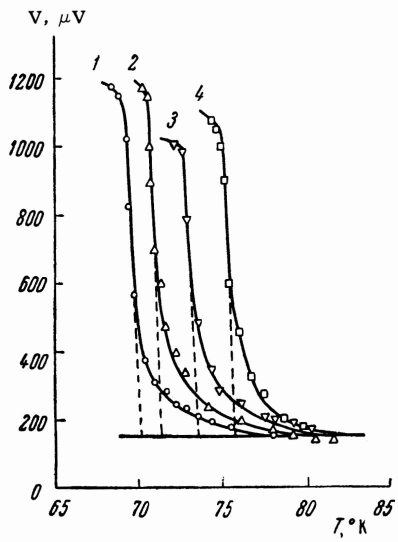

FIG. 1. Temperature dependence of the induced emf in the measuring coil at various pressures: 1) p = 1 atm, Θ = 70.3°K; 2) p = 2.2 katm, Θ = 71.3°K; 3) p = 8.3 katm, Θ = 73.6°K; 4) p = 11.8 katm, Θ = 75.6°K.

temperature of EuO was 70.3°K at atmospheric pressure. This result was in satisfactory agreement with the value of 71.5°K, obtained for the same samples of EuO by the thermodynamic coefficient method.[6] The method we used did not give a highly accurate absolute value of the Curie temperature but it was very convenient at high pressures and was sufficiently sensitive in the determination of the shift in the Curie temperature with pressure. It should be mentioned also that the absolute value of the induced emf could not be regarded as an unambiguous characteristic of the behavior of the magnetization under compression, since it depended on a number of secondary factors associated with the experimental method.

The obtained pressure dependence of the Curie temperature shift of the oxide EuO is shown in Fig. 2, which indicates that, in the pressure range from atmospheric to 12 katm, the Curie temperature increases linearly with pressure and the pressure coefficient of the Curie temperature shift is

$$d\Theta / dp = (4 \pm 1) \cdot 10^{-4} \text{ deg/atm}.$$

We did not observe any permanent changes in the Curie temperature after the removal of high pressure.

The influence of elastic stresses on the ferromagnetic transition temperature is explained by the thermodynamic theory of second order phase transitions. Expanding the thermodynamic potential near the Curie point as a series in powers of the order parameter and of the elastic stresses, Belov[7] obtained a linear dependence of the Curie temperature shift on uniform elastic stress. The existence of such a dependence was confirmed by a number of experimental investigations dealing with the ferromagnetic transition.[8-10] However, a subsequent, more detailed analysis of the expansion of the thermodynamic potential into a series yielded a theoretical prediction of a nonlinear dependence of the Curie temperature on pressure (cf., for example, [11]) which, in particular, was observed in Invar alloys.[12] It is possible that a nonlinear dependence may be observed in substances in which this effect is large at sufficiently high pressures.

Usually, the data on the magnitude and sign of $d\Theta/dp$ is of interest in connection with the dependence of the exchange interaction on the interatomic spacings. Using our results, we could estimate approximately the dependence of the Curie temperature of the oxide EuO on the changes in the lattice parameter under uniform compression up to 12 katm. If the lattice parameter does not change too much, so that the change in the total number of spins taking part in the exchange interaction may be ignored, we have

$$\frac{d\Theta}{da} = \frac{d\Theta}{dp}\frac{dp}{da} \approx -\frac{3}{\varkappa a}\frac{d\Theta}{dp}, \tag{1}$$

where a is the lattice parameter and κ is the compressibility of the substance.

The compressibility of the paramagnetic phase of EuO at room temperature was determined by the piston displacement method. Within the limits of the accuracy of this method, we could neglect the temperature dependence of the compressibility, assuming that $\kappa(77°\text{K}) \approx \kappa(300°\text{K})$, because in the expansion

$$\varkappa(77°\,\text{K}) \cong \varkappa(300°\,\text{K})\left(1 - \frac{1}{\varkappa(300°\,\text{K})}\frac{\partial\varkappa}{\partial T}\Delta T\right) \tag{2}$$

the second term in parentheses is of the order of

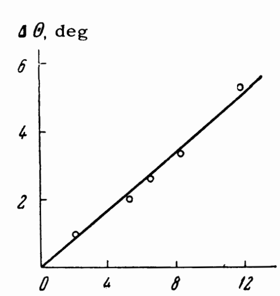

FIG. 2. Pressure induced shift of the Curie temperature of the compound EuO.

10^{-3} [κ (300°K) ≈ 10^{-6} kg^{-1} cm^2, $\partial\kappa/\partial T$ ≈ 10^{-11} kg^{-1} cm^2 deg^{-1}, ΔT ≈ 10^2 deg]. Moreover, it was known that in the range of temperatures considered, the EuO did not undergo phase transitions of the first kind. The compressibility anomaly at the Curie point was outside the limits of the sensitivity of the method and, therefore, we assumed that the value of the compressibility of the ferromagnetic phase differed only slightly from the compressibility of the paramagnetic phase. Using Eq. (1), we could then estimate approximately the value of $d\Theta/da$:

$$d\Theta / da = (160 \pm 50) \text{ deg/Å}$$

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