Anomalies in the thermo-emf and resistance of cadmium-magnesium alloys at low temperatures

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The thermo-emf and resistance of cadmium-magnesium alloys for Mg concentrations in the range $0 < x < 20$ at.% at liquid-helium temperatures were measured. Characteristic singularities are observed at Mg concentrations of 6 and 11 at.%. Their relation to topological changes at the Fermi surface of cadmium at the K and L points of the Brillouin zone is discussed.

Direct interest in the study of 2.5-order transitions[1] in alloys increased considerably after the recent appearance of a theoretical paper[2] in which the characteristic singularities in the electrical conductivity and in the thermo-emf in lithium-magnesium alloys accompanying the transition were calculated. Such anomalies were indeed observed experimentally in previous investigations[3] at magnesium concentrations for which the Fermi surface touches the boundary of the Brillouin zone. In this case, however, there are certain difficulties, arising due to martensite transformations in these alloys, in the quantitative interpretation of the observed effects.

In this letter we use a new approach to the study of 2.5-order transitions in cadmium, in which as the concentration of the isovalent impurity is increased, the magnesium lattice remains hexagonal at all temperatures and only the change in the ratio c/a plays the role of the variable parameter. From this point of view, cadmium alloys with magnesium represent an extremely interesting object for studying Lifshitz singularities accompanying topological transformations, first because in cadmium several singularities are situated near the Fermi level and, second, because these transitions occur not only due to discrete action (impurity) but also due to continuous action

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(temperature, anisotropic load, pressure), which makes it possible to perform comprehensive investigations and to compare different methods.

At temperatures $T > 250$ °C the $Cd_{1-x}Mg_x$ alloys form a continuous series of disordered solid solutions in the entire range of concentrations.[4] At lower temperatures the ordered structures Cd_3Mg, CdMg, and $CdMg_3$ appear at concentrations $0.2 < x < 0.8$, which is manifested in the behavior of the kinetic coefficients measured at room temperature.[5] At concentrations $x < 0.2$, an ordered structure apparently no longer arises and only anomalies due to 2.5-order transitions can be observed. In this interval of magnesium concentrations ($x \lesssim 0.2$) the ratio c/a changes considerably[6,7] from 0.89 at $x = 0$ up to 0.74 at $x = 0.2$. The change in c/a determines a number of topological changes in the Fermi surface of cadmium: formation of bridges in the "monster" and the appearance of electronic cavities near the points K ("needles") and L ("butterflies"). This problem has been studied extensively, both experimentally and theoretically.[8] Nevertheless, only the anomaly in the magnetic susceptibility[9] has been clearly observed experimentally and only in a direction along the hexagonal axis of the crystal ($\chi_{||}$).

In this study we measured the resistance and thermo-emf of the alloys $Cd_{1-x}Mg_x$ for $0 < x < 0.2$, i.e., for concentrations at which all alloys are in a state of the disordered solid solution. The components were melted in an induction furnace in a graphite crucible in an atmosphere produced by evaporating helium. The samples for the measurements were obtained by drawing the sample out of the melt into a graphite capillary and had the characteristic dimensions of $0.6 \times 1 \times 25$ mm. The resistance ratios of the starting materials were $R_{300}/R_{4.2} \simeq 4000$ for Cd and $\simeq 300$ for Mg. The concentration x was determined from weighted quantities of Mg and Cd prior to melting. The thermo-emf was measured by a differential method relative to the superconducting Nb_3Sn in the temperature range $2 < T < 14$ K with switching of the heat flow as done previously.[3]

The results of the measurements are shown in Fig. 1. The lower curve shows the concentration dependence of the coefficient in the linear part of the temperature dependence of the thermo-emf $\alpha(T)$ (on the left). The upper curve shows the concentration dependence of the residual resistance, given in the scale $\rho_{4.2}/x(1-x)$, as in Ref. 2; here $\rho_{4.2} = R_{4.2}/R_{300} - R_{4.2}$. It is evident that at a concentration of $x \simeq 11\%$ a large peak is seen in the dependence $\alpha'_T(x)$ which correlates with the break in the $\rho(x)$ curve. A less distinct singularity is observed at a concentration of $x \simeq 6\%$. Note the considerable "dropout" of points at $x = 19.1\%$ from both curves, apparently suggesting that partial ordering of the Cd_3Mg compound occurs at this concentration.

Comparison of these results with measurements of the susceptibility of a single-crystalline sample[9] shows that the anomaly observed by us at $x \simeq 6\%$ basically coincides with the peak in $\chi_{||}$ at $x \simeq 6.5\%$, which Svechkarev *et al.*[9] attribute to a 2.5-order transition involving the formation of six "needles" at the K points. Taking into account the analysis of the arrangement of the energy levels in cadmium,[8] it is natural to assume that the sharper peak in the thermo-emf at $x \simeq 11\%$ corresponds to a 2.5-order transition accompaning the formation of 12 electronic cavities ("butterflies") at the points L, especially since this peak is accompanied by an appreciable characteristic break in the resistance, in accordance with the theoretical curve in Fig. 2a in Ref. 2. In

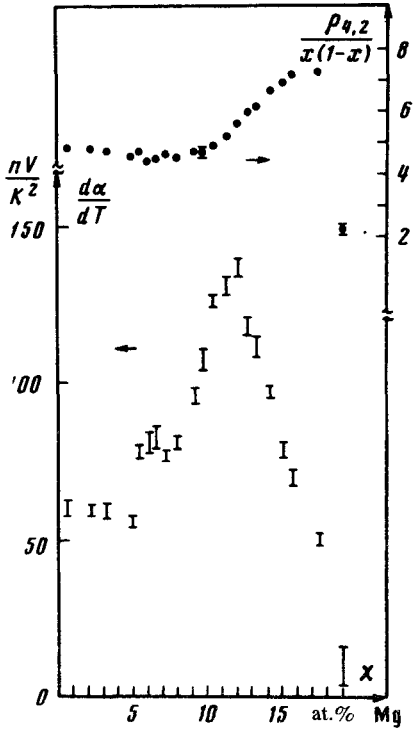

FIG. 1. The resistance and thermo-emf vs magnesium concentration. The upper curve (scale on the right) shows the reduced residual resistance $\rho_{4.2}/x(1-x)$, where $\rho_{4.2} = R_{4.2}/R_{300} - R_{4.2}$. The lower curve (scale on the left) shows the coefficient in the linear part of the temperature dependence of the thermo-emf α'_T.

Ref. 9, in this region of concentrations, i.e., at $x \simeq 10\%$, only the break in $\chi_{||}(x)$, is observed and no singularities are observed in $\chi_{\perp}(x)$.

We will first establish a nontrivial fact, in our opinion, that the smearing of the Fermi surface in disordered alloys is so small at low temperatures that the 2.5-order transitions occur at very narrow separations in energy and hence in Mg concentration in polycrystalline samples, even in a metal with such a complex Fermi surface. This conclusion is consistent with the fact that the smearing of the Fermi energy is determined by the energy relaxation time. At liquid-helium temperatures this time is much longer than the momentum relaxation time, which determines the residual resistance.

Comparison of these results with susceptibility data shows a qualitative agreement, although the electronic transitions are not manifested in the same way in both transitions. The strongest singularity at $x \simeq 11\%$, which is associated with the formation of butterflies, does not appear in the susceptibility measurements. At present, it is difficult to explain the observed differences,but the information obtained in the measurements of the thermo-emf can, in our opinion, be given a clearer theoretical interpretation.

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