

Electron topological transitions in indium under pressure

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Structural features are observed to arise in the thermal emf α of indium upon a pressure-induced topological change in the Fermi surface. The positions of the transitions along the energy scale are determined. The amplitude of the anomaly for pure indium increases with increasing temperature, in contrast with the behavior expected on the basis of the present understanding.

Volynskii *et al.*¹ analyzed the nonmonotonic dependence of $\partial T_c \partial p$ in indium on the impurity concentration and suggested as a result that two topological transitions may occur in this material near the Fermi energy ϵ_F .

An electron topological transition is known to be accompanied by sharp structural features in the behavior of the thermal emf α (see Ref. 2 and the literature cited there). In the present letter we report a study of α in indium under pressures up to 12 kbar.

The method used for measuring α under pressure in the present experiments is similar to that used previously.² The test samples are prepared by extruding the material through a window ranging in diameter from 3 to 1 mm. Samples of several compositions were studied: 1) pure indium ($RRR \cong 11\,000$); 2) indium + 0.09% mercury ($RRR \cong 640$); 3) indium + 0.8% mercury ($RRR \cong 70$); 4) indium + 2.5% cadmium ($RRR \cong 14$).

Figure 1 shows the results of the measurements of αT^{-1} for samples 1 and 2 at various pressures. The significant increase in αT^{-1} in the case of sample 1 is a consequence of phonon drag. The maximum on the $\alpha T^{-1}(T^2)$ curves at $T \sim 6$ K is due to the onset of transfer processes in the phonon system. Mercury was selected as the basic impurity since it suppresses phonon drag, as can be seen from the curves of $\alpha T^{-1}(T^2)$ for sample 2.

The quantity αT^{-1} is plotted as a function of the pressure at the right in Fig. 1 at fixed temperatures, marked at the left by the dashed lines. Corresponding curves for samples 3 and 4 at $T = 5$ K are shown in Fig. 2. The clearly defined anomalous features at the right in Fig. 1 and in Fig. 2 indicate topological changes in the Fermi surface. It can be seen from the asymmetry of the $\alpha T^{-1}(\rho)$ curves that new electron regions form as the pressure is increased in samples 1 and 2, while in samples 3 and 4 a neck appears between electron sheets of the Fermi surface.

According to data on the Fermi surface,^{3,4} in samples 3 and 4 the connectedness of the ring of β tubes in the third zone is restored; this connectedness had been disrupted by the introduction of the mercury or cadmium impurity. The structural features in the cases of samples 1 and 2 are probably due to the appearance of α tubes or of electron pockets at W points in the third Brillouin zone.⁵

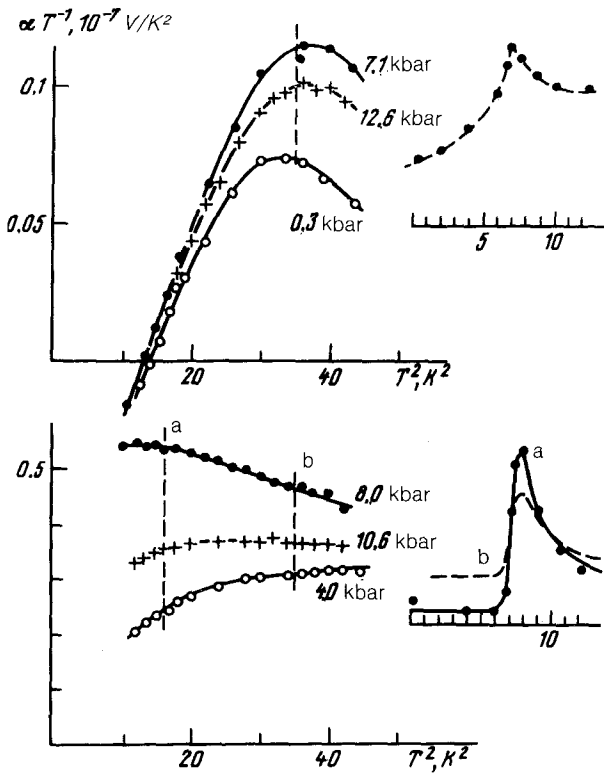


FIG. 1. Results of the measurements of the thermal emf α of pure indium (top) and of indium containing 0.09% Hg (bottom) at various pressures (the curve labels). Shown at the right is the pressure dependence of αT^{-1} at the temperatures indicated by the dashed lines.

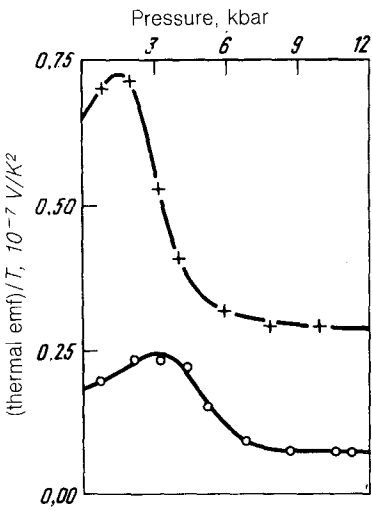


FIG. 2. Pressure dependence of αT^{-1} at $T = 4$ K for indium samples containing 0.8% Hg (upper curve) and 2.5% Cd (lower curve). The reason for the difference in the thermal emf's of the two samples is the difference in the impurity species.

There is a good quantitative agreement between the nature of the structural features found for samples 2, 3, and 4 on the one hand and the existing theory,^{2,6} on the other. At the bottom right in Fig. 1 and in Fig. 2, all the curves connecting the experimental points have been drawn from the relation $\alpha T^{-1} = \alpha_0 T^{-1} + \delta \alpha T^{-1}$, where

$$\delta \alpha T^{-1} = A \int_{-\infty}^{+\infty} y \text{ch}^{-2} \frac{y}{2} \left\{ B + yT + [(B + yT)^2 + (\Gamma/2)^2]^{1/2} \right\}^{1/2} dy, \quad (1)$$

$$B \equiv (\epsilon_F - \epsilon_c)_0 + \frac{\partial(\epsilon_F - \epsilon_c)}{\partial p} p,$$

ϵ_F and ϵ_c are the Fermi energy and its critical value, and $\Gamma \equiv \hbar/\tau$ is the quasiparticle damping near the topological transition, $\epsilon_F = \epsilon_c$.

Applying (1) to the experimental data on sample 2, we find $(\epsilon_F - \epsilon_{c1})_0 \approx -115$ K, $\partial(\epsilon_F - \epsilon_{c1})/\partial p \approx 16$ K/kbar, and $\Gamma \lesssim 10^{-2}$ K. In view of the shift of the maximum on the curve of $\alpha T^{-1}(P)$ for this sample with respect to its position for sample 1, we find $\partial(\epsilon_F - \epsilon_{c1})/\partial C \approx 113$ K% (c is the atomic concentration of mercury). Knowing these values for pure indium, we find $(\epsilon_F - \epsilon_{c1})_0 \approx -105$ K. For the case in which the connectedness of the β ring is disrupted, we find the estimate $(\epsilon_F - \epsilon_{c2})_0 \approx +80$ K. This value agrees well with that found from measurements of the de Haas-van Alphen effect.⁴ The values found for $(\epsilon_F - \epsilon_{c1})_0$ and $(\epsilon_F - \epsilon_{c2})_0$ are substantially higher than the estimates given in Ref. 1.

Expression (1) gives a good description of the temperature dependence and the relationship between the heights of the anomalous features in $\delta \alpha T^{-1}(p)$ (Fig. 3) for samples 3 and 4. The sharper decrease in the amplitude of the effect with increasing temperature which is observed for sample 2 can be understood by taking into account the role played by electron-phonon scattering in the kinetics of the electrons¹⁾ (Ref. 6).

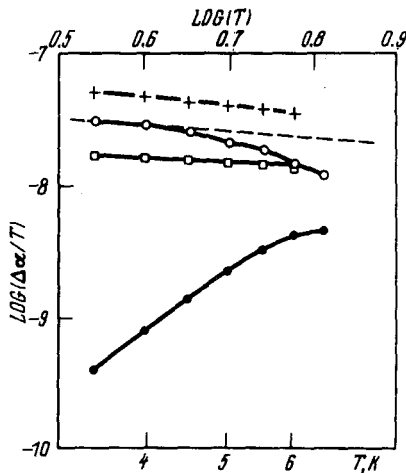


FIG. 3. Temperature dependence of the anomalous features, i.e., the dependence of $\Delta \alpha T^{-1} = [\alpha(p_1, T)_{\max} - \alpha(p_2, T)_{\min}]/T$ on the temperature T , for various samples (p_1 and p_2 are the pressures at which α reaches its maximum and minimum values, respectively, at the temperature T). +—In + 0.8% Hg; O—In + 0.09% Hg; □—In + 2.5% Cd; ●—pure In. The dashed line shows the law $\sim T^{-0.5}$.

The temperature dependence of the anomalous feature for pure indium (sample 1) was unexpected. There is a significant increase in the height of this feature with increasing temperature. The shape itself of the anomalous feature is not the classical shape that we see in sample 2, although we are dealing with a purer sample, in which the damping of electrons is another 20 times lower.

Interestingly, the feature reaches a significant magnitude at 5–7 K, where transfer processes in the phonon system lead to an equilibrium for this system.

We wish to thank I. M. Suslov for useful discussions.

¹⁾ In samples with the lower mercury content ($RRR = 2200$ and 6500) we subsequently observed a sharper decrease in $\Delta\alpha T^{-1}$ as the temperature was increased to ~ 6 K. We note again that these samples exhibit no substantial contribution of phonon drag to the thermal emf.

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