Anomaly in the longitudinal magnetothermal emf of cadmium near an electron topological transition under pressure

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The thermal emf of cadmium has been measured in a longitudinal magnetic field up to 60 kOe at pressures up to 30 kbar. The curves of $E(P)|_{H=\mathrm{const}}$ exhibit a clearly defined extremum near an electron topological transition.

Theoretical research (e.g., Refs. 1 and 2) and experimental research[3,4] on the thermal emf upon a change in the connectedness of the Fermi surface show that this emf has a significant anomaly in the region of an electron topological transition. Different mechanisms contribute differently to the thermal emf in the transition region, and the theoretical analyses carried out by different groups of investigators have sometime led to contradictory results.[1,2]

We believe that a study of the thermal emf in a strong magnetic field might yield important additional information for a further study of the electron topological transition and its consequences. Unfortunately, the theory on this matter is clearly inadequate, and we know of no studies of the behavior of the magnetothermal emf in the vicinity of the electron topological transition.

In this regard cadmium is a convenient and interesting substance: The appearance of new parts of the Fermi surface—evidence of an electron topological transition[5]—has been observed in cadmium by a direct method (by means of the de Hass-van Alphen effect). Specifically, at $P \gtrsim 17$ kbar, the "sleeves" of the hole "monster" join in the second zone, and an electron "needle" appears in the third zone.

In this letter we report measurements by a differential method of the thermal emf of a cadmium single crystal in a magnetic field $H \| \nabla \| \Delta E$ up to 60 kOe at pressures up to 30 kbar at liquid-helium temperatures. The experimental procedure was similar to that described in Ref. 6. Measurements were taken at an average sample temperature of 2.5–5 K (the bath temperature was 1.7–4.2 K); the temperature gradient along the sample was ~ 1.5 K. The sample had a resistance ratio $R_{300\,K}/R_{4.2\,K} \sim 5000$. The magnetic field was directed along the [0001] hexagonal axis. Measurements were taken at fixed values of the magnetic field.

The curves of the magnetothermal emf versus the magnetic field constructed from our data exhibit a clear tendency toward saturation at pressures below and above the pressure corresponding to the electron topological transition (Fig. 1). This behavior of the magnetothermal emf agrees with the present theoretical understanding[7] (which ignores the electron topological transition), according to which, for various types of Fermi surfaces, and in our experimental configuration, we should observe a saturation of both the diffuse part of the magnetothermal emf and the phonon-drag magnetothermal emf. Actually, the $E(H)$ curves constructed for pressures near the electron topological transition have a completely different shape (Fig. 1). The tendency toward saturation disappears from them.

The anomalous behavior of the longitudinal magnetothermal emf can be seen even more clearly on the curves of $E(P)$ at fixed values of the magnetic field (Fig. 2).

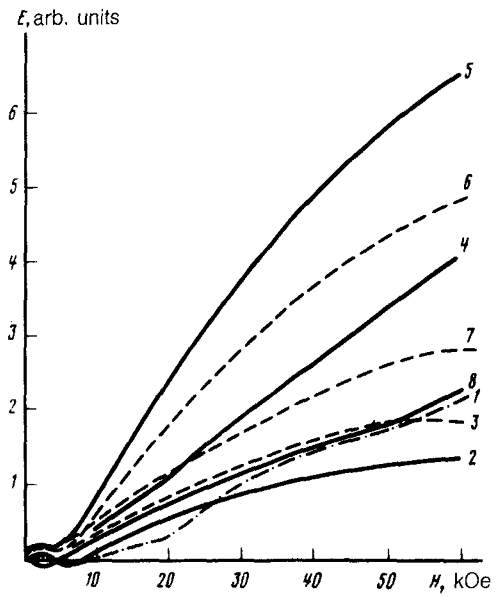

FIG. 1. Field dependence of the longitudinal magnetothermal emf at various pressures: 1—1.4; 2—7.2; 3—13.1; 4—15.9; 5—19.2; 6—20.5; 7—25; 8—29 kbar.

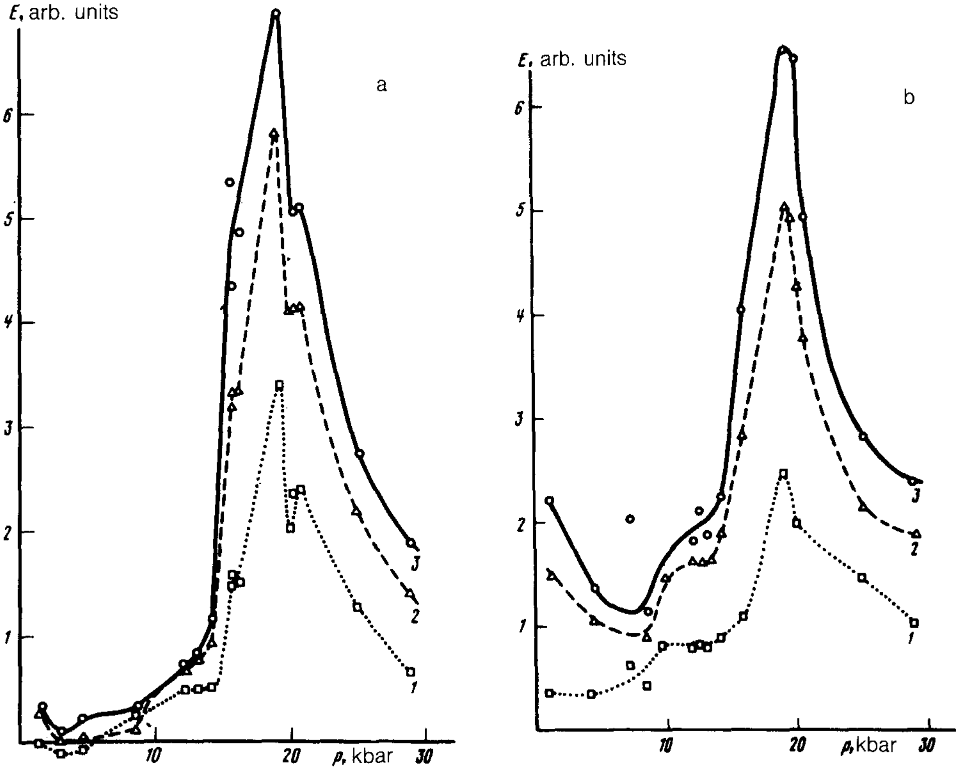

FIG. 2. Baric dependence $E(P)|_{H=\mathrm{const}}$. a—$T_{\mathrm{sample}}=2.5$ K; b—$T_{\mathrm{sample}}=5$ K. 1) $H=20$ kOe; 2) $H=40$ kOe; 3) $H=60$ kOe.

We also see that the anomalous increase in the signal sets in several kilobars before the point at which the new part of the Fermi surface appears, and it does not disappear until several kilobars beyond this point. It is thus not possible to distinguish the contributions from these two types of electron topological transitions. At best we can suggest that the small peak seen on the slope of the $E(P)|_{H=\mathrm{const}}$ curve at $T=2.5$ K is a manifestation of a second transition.

At the electron topological transition, the thermal emf of the cadmium in the absence of a magnetic field also has a clearly expressed anomaly[8] at $P \geqslant 16$ kbar. However, the magnitude of this anomaly, for both cadmium and the other metals which have been studied in this regard,[3,4] is relatively much smaller than the anomaly in the magnetothermal emf.

A point should be made here: The measured value also contains a component from the magnetothermal emf of the measurement lead conductors. It would be extremely difficult to deal with this contribution exactly, but the absence of anomalies from the well-studied kinetic properties of Pb at pressures in the range studied here[9] allows us to attribute the observed anomaly to an electron topological transition in cadmium.

In summary, a new effect has been observed: a pronounced increase in the magnitude of the longitudinal magnetothermal emf near an electron topological transition. The mechanism for this effect obviously requires a separate theoretical study.

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