

# Magnetic-field-induced Mott transition in $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$

A. B. Aleĭnikov, P. I. Baranskii, and A. V. Zhidkov

*Institute of Semiconductors, Academy of Sciences of the Ukrainian SSR*

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The  $\rho_{\perp}(H)$  dependence has been studied at 4.2 K, in the extreme quantum limit, in  $n$ -type  $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$  ( $x = 0.13$ – $0.19$ ). The magnetic field induces a metal-nonmetal transition (a Mott transition). This transition has some distinctive features in these crystals.

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Theories<sup>1,2</sup> for the magnetoresistance at magnetic fields corresponding to the extreme quantum limit ( $\hbar\omega \gg kT$ ;  $\hbar\omega > E_F/kT$ ) predict  $\rho_{\perp}(H) \sim H^{\alpha}$  in the one-electron approximation, where  $\alpha$  is approximately constant if there is only one scattering mechanism. Under the condition  $R/\lambda \gg 1$ , however, where  $R$  is the Debye screening radius and  $\lambda \equiv \sqrt{\hbar c/eH}$  is the magnetic length, the one-electron approximation breaks down.<sup>2</sup> In an effort to determine the behavior of the magnetoresistance under these conditions we have measured the field dependence  $\rho_{\perp}(H)$  at  $T = 4.2$  K in  $n$ -type  $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$  single crystals ( $x = 0.13$ – $0.19$ ). The basic characteristics of these crystals are listed in Table I.

In the impurity band of semiconductors which exhibit a metallic conductivity, a magnetic field substantially contracts the wave functions of the impurity states,  $a_H$ , and should cause a Mott transition<sup>3</sup> under the condition

$$N^{1/3} a_H = 0.37, \quad (1)$$

where  $N$  is the electron concentration.

Because of the rather high dielectric function,  $\kappa \approx 14.1$ , and the small ratio  $m^*/m_0 \approx 0.005$ – $0.008$ , the dimension of the wave functions at  $H = 0$  is  $a_0 \approx 1300$  Å in these crystals.

TABLE I. Basic characteristics of the samples.

Nº	$N, \text{ cm}^{-3}$	$\lambda_c, \text{ cm}$	$\sigma_{\min}^{\text{theo}}, \text{ mho/cm}$	$\sigma_c, \text{ mho/cm}$
1	$1.80 \times 10^{14}$	$3.25 \times 10^{-6}$	0.65	0.58
2	$1.96 \times 10^{14}$	$3.12 \times 10^{-6}$	0.66	0.59
3	$2.20 \times 10^{14}$	$2.97 \times 10^{-6}$	0.69	0.59
4	$2.60 \times 10^{14}$	$2.70 \times 10^{-6}$	0.73	0.60
5	$1.25 \times 10^{15}$	$1.59 \times 10^{-6}$	1.23	2.60
6	$1.56 \times 10^{15}$	$1.54 \times 10^{-6}$	1.33	2.17

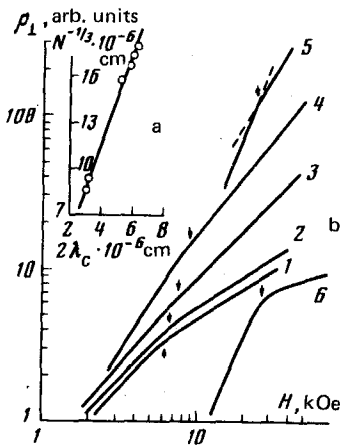


FIG. 1. a—Dependence of the parameter  $N^{-1/3}$  on the effective radius of the localization by the magnetic field,  $2\lambda_c$ , at the point of the Mott transition. The solid line is theoretical, calculated from Eq. (1); the points are experimental data obtained from the samples available; b—field dependence of the transverse magnetoresistive effect of  $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$  samples at 4.2 K, in the extreme quantum limit. The curves are labeled with the designations of the samples.

tals. In this case the impurity atoms can form an impurity band, which merges with the bottom of the conduction band; the impurity atoms may also generate discrete energy levels in the interior of the conduction band.

Since the radial part of the envelope of the wave function of an impurity center in the case  $a_0 \gg \lambda$  decays in accordance with  $\exp[-\rho^2/(2\lambda)^2]$ , according to Ref. 4, the value of  $2\lambda$  in this case is an effective localization radius, so that the satisfaction of condition (1) is ensured at a certain  $H_c$ . In this case, the magnetic field confines electrons to a plane perpendicular to itself and is more effective than the Coulomb potential; the curves of  $\rho_1(H)$  should exhibit structural features at the values  $H=H_c$  (which differ for the different  $N$ ), in agreement with experiment (see the slope changes on curves 1–6 in Fig. 1). In Fig. 1a, the experimental values of  $N^{-1/3} = f(2\lambda_c)$  conform well to a straight line drawn in accordance with (1) for the conditions corresponding to a Mott transition.

Let us compare the conductivity of the samples at the transition point with the corresponding values of the “minimum metallic conductivity”<sup>5</sup>  $\sigma_{\min} = Ae^2/\hbar a$ , where  $a = 0.55 N^{-1/3}$  is the average distance between electrons, and  $A = 0.026\text{--}0.1$  is a coefficient which depends on the coordination number. Comparison of the measured values of  $\sigma_c = \rho_c^{-1}$  (Table I) with those calculated for  $A = 0.026$ , i.e., for a random arrangement of the centers, shows that at  $H=H_c$  we do in fact observe, within the experimental errors, the “minimum metallic conductivity” corresponding to the conditions under which a Mott transition occurs.

The various pieces of evidence thus indicate that, under the conditions corresponding to the extreme quantum limit, a magnetic field induces a Mott transition in  $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$  at  $T=4.2$  K. The transition is induced because the magnetic field localizes electrons, and this effect causes an impurity band to split off from the conduction band. A characteristic of the Mott transition in this case is that the conduction band still has a significant number of carriers, because the impurity band is narrow and the gap between the impurity band and the conduction band is small ( $\sim 0.3$  meV—comparable to  $kT$  under the conditions of the present experiments). The significant number of carriers in the conduction band prevents a sharp change in the nature of the  $\rho_1(H)$  dependence at the transition point.<sup>6</sup>

What appears to be a similar structure has been observed previously on the  $\rho_{\perp}(H)$  curves for degenerate conductors (metals).<sup>7,8</sup> The structure was attributed in those papers to magnetic breakdown.<sup>9</sup> However, the magnetic field at which magnetic breakdown is attained could only increase with decreasing concentration  $N$ . For this reason, an explanation of the structure observed by us on the  $\rho_{\perp}(H)$  curves in terms of the magnetic breakdown would explicitly contradict the data in Fig. 1.

A similar structure was observed on  $\rho_{\perp}(H)$  curves in Refs. 10 and 11, where it was linked to a Wigner crystallization of the electron gas in a magnetic field.

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