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# DEMONSTRATION OF SHUBNIKOV-DE HAAS EFFECT IN A THIN FILM OF AMORPHOUS $Cd_3As_2$

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We have found in a thin amorphous film of $Cd_3As_2$, in a magnetic field above 10T, a sharply defined series of Shubnikov-de Haas oscillations, indicating the existence of Landau states of very small width. The effective mass is found to be perfectly isotropic and $\sim .1m_0$ (cf. an anisotropic mass of $\approx .03m_0$ at the same energy in monocrystalline $Cd_3As_2$). Above 10T the amplitude and hence the effective mobility rise very rapidly. Our results suggest that crystalline order is not essential for sharp Landau quantization, though we believe that local order may be.

## Introduction

Thin films of amorphous $Cd_3As_2$ were produced at Zabrze [1,2,3] by thermal evaporation of crystalline $Cd_3As_2$ placed in a molybdenum crucible. They are deposed on a mica substrate at room temperature in an evaporation chamber at a vacuum of $\approx 10^{-6}$Torr.

The films have a thickness ranging from .5 to 10μ. The active surface is $\approx 3 \times 1$ mm$^2$. The Hall probes are precisely aligned and the electronic contacts are made by evaporation of gold.

The microstructure of the amorphous film is composed of agglomerates [1-3] with grains of rounded or elongated fibrous form whose dimensions depend on the conditions of deposition [4]. The influence of substrate temperature, rate of deposition and deposition chamber pressure have been investigated in a kinetic study of the transformation from amorphous to crystalline state [1,5]. For samples prepared at room temperature typical grain dimensions are $\approx$500 - 1000Å. It is possible to obtain two distinct groups of amorphous films: one rapidly deposed and having a high resistivity (1-10KΩ) and weak Hall mobility (10-50 cm$^2$/Vsec) at room temperature and the other deposed slowly, with relatively low resistivity (300-1000Ω) and mobility from 200 to 500 cm$^2$/Vsec. It is the latter group which was used in our experiments.

The amorphous structure has been studied by X-ray diffraction and by scanning electron diffraction [5] on a film detached from its substrate. The study of the radial distribution function by Fourier

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analysis has shown that the interatomic coordination number of the atoms of As and Cd in the amorphous materials is different from (lower than) that of monocrystalline samples. No significant coordination is found for an interatomic distance $\gtrsim 10$Å. There is however local order, extending over 3 or 4 atoms. X-ray studies [1] have not shown any points of diffraction.

## Experimental Results

Shubnikov-de Haas oscillations have been studied both in the Hall voltage and resistivity using the Toulouse pulsed magnetic field ($\leq$ 38T). Longitudinal and two transverse configurations have been used, at temperatures of 4.2 and 20K. The oscillation spectrum has been extracted either by a technique of linear compensation with field or by that of second differentiation.

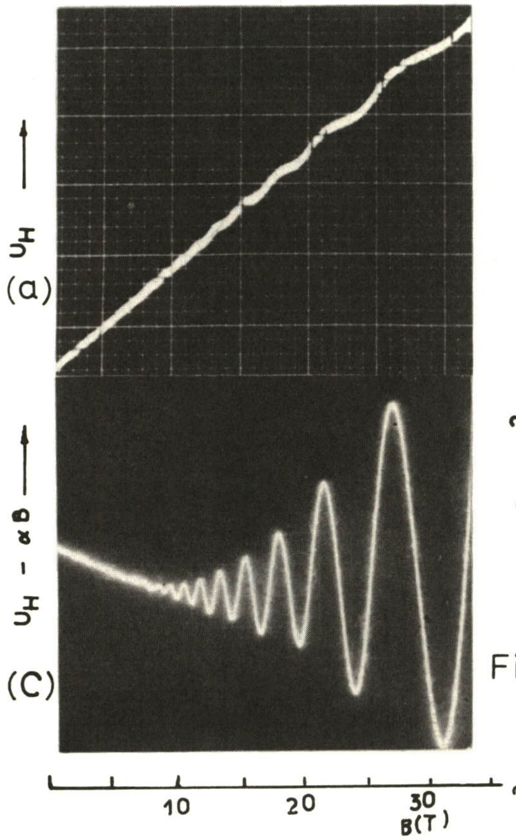
Figure (1a) shows the monotonic variation of Hall voltage from which the oscillatory part was obtained by linear compensation [Fig. (1e)] and by second differentiation [Fig. (1e)]; figure (1b) shows the monotonic part of the transverse resistivity from which the oscillatory part was obtained by second differentiation [Fig.(1d)].

The Shubnikov-de Haas oscillations which appear for magnetic field >10T in both Hall voltage and resistivity are quite comparable with those found for monocrystalline samples in which the low field mobility is 150 times greater or polycrystalline ones in which it is ten times larger [6]. The non-oscillatory part of the Hall voltage is effectively linear, while the resistivity has approximately a $B^2$ dependence.

The existence of the oscillations shown in figs. (1a) and (1b) is very surprising. In the first place, they indicate a mobility for B > 10T very much higher than the Hall mobility at 4.2K and weak field, which is already high for an amorphous material. Secondly, the rise in amplitude of the oscillations with field is striking. Finally, the periodicity of the oscillations indicates an electron concentration much higher than that deduced from the classical Hall effect formula. However, the granular character of the material observed under the electron microscope indicates that the use of this formula is very questionable in the present context.

The observed granular character, with grains typically of $\approx$1000Å, suggests the possibility of a high mobility inside the grains, while the low conductivity is due to scattering at grain boundaries.

Using the classical formula for the relative amplitudes of successive oscillation peaks (applicable at high field and low temperature) we can deduce the variation of the apparent microscopic mobility shown in figure ( 2). This rapid rise is quite different from that found in polycrystalline samples [7]. It is, however, consistent with the observation that, above 10T, the cyclotron orbit of electrons at the Fermi surface becomes sufficiently small compared with grain size to permit the existence of weakly broadened Landau states inside the grains; with increasing field both the cyclotron radius and the Landau quantum number at the Fermi level decrease and more such states are possible. It is these states which presumably give rise to the oscillations. Thus at 10T, where we are concerned with the 12th Landau level the radius of the cyclotron orbit is $\simeq$450Å; at higher fields it decreases as $\sim B^{-1}$.



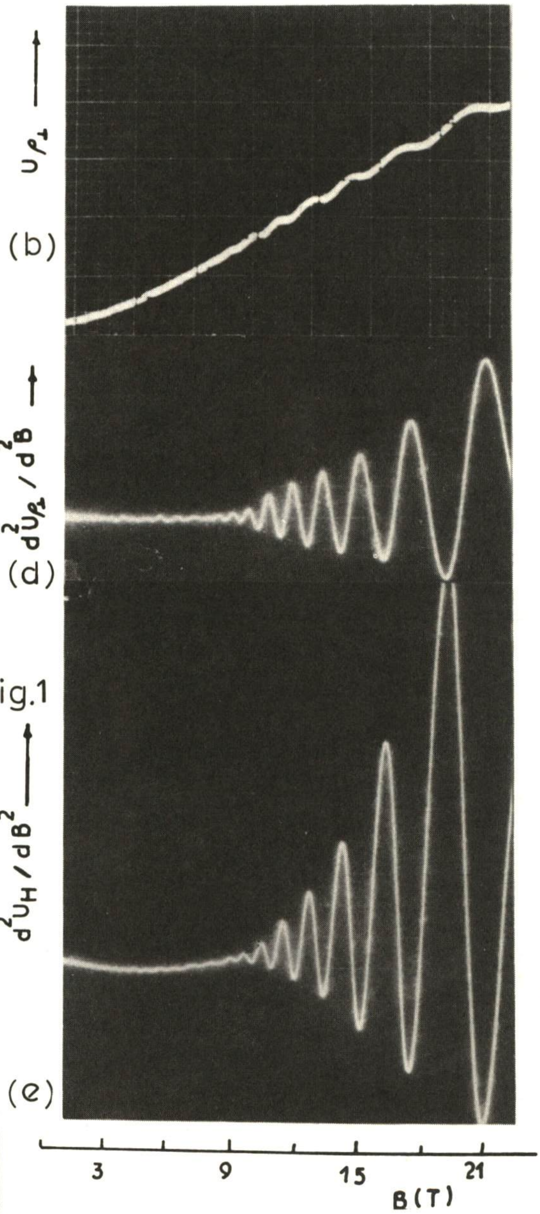




Fig.1

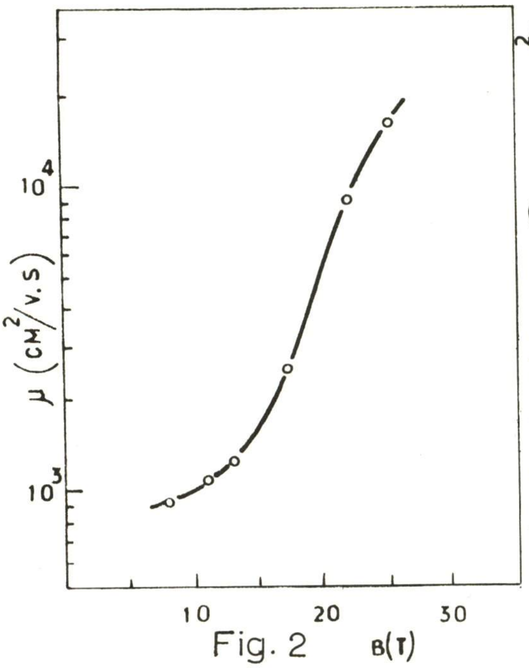



Fig. 2

Figure 1
Field dependence of: (a) Hall and (b) transverse magnetoresistance voltages. (c) Hall voltage after compensation. Second derivatives of (d) $U_{\rho\perp}$ and (e) $U_H$

Figure 2
Typical variation with B of effective microscopic mobility $\mu_c$

The existence of quantized states in an amorphous material suggests that the electron states can be treated in the effective mass approximation. As suggested by Kivelson and Gelatt [8], this can follow from the assumption that the wave function can be treated as the product of a rapidly varying "molecular" function and a slowly varying envelope function which satisfies a Landau equation with an effective mass depending on the molecular function. The spatial variation of the effective mass expected in a completely disordered material should be largely suppressed when, as in amorphous $Cd_3As_2$, there is local order.

The effective mass has been determined in the usual manner for a number of samples. Unlike in the case of crystalline $Cd_3As_2$, it is found to be completely isotropic; and is about three times larger at the same energy. There appears to be a small variation with Fermi energy and therefore carrier concentration, as shown in the following table.

| Sample | 127/77 | 3 | 127/75 | 7 |
|---|---|---|---|---|
| Effective mass/$m_0$ | .101 | .102 | .095 | .082 |
| Fermi level (e.v.) | .135 | .126 | .130 | .117 |
| Carrier concentration/$10^{18}cm^{-3}$ | 7.1 | 6.6 | 6.5 | 4.2 |
| Mobility (low field) $cm^2/Vsec$ | 263 | 620 | 498 | 436 |
| SdeH periodicity $^1/(10^2$ Tesla) | .86 | .91 | .95 | 1.22 |

We have estimated the carrier density from the periodicity of the oscillations using the experimentally determined effective mass and the parabolic band approximation. The observation of oscillations, the strong electron concentration and the weak mobility gap (~0.4eV [4])suggest that the conduction is due to a degenerate electron distribution in non-localized states.

Finally, we note (Figs.1d,1e)that, just as in the case of monocrystalline samples of $Cd_3As_2$, the extrema of the oscillations in resistivity and Hall voltage are opposite in phase.

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1) L. Zdanowicz and S. Miotkowska, Thin Solid Films 29 (1975) 177; J. Crystal Growth 48 (1980) 387.
2) M. Niedzwiedel and L. Zdanowicz, J. Non-Crystalline Solids 23 (1977) 267.
3) J. Jurusik and L. Zdanowicz, Thin Solid Films 67 (1980) 285.
4) L. Zdanowicz and C. Weclewicz, International Conference on Amorphous Semiconductors, Budapest, Akademai Krado, Budapest 1976, 437.
5) A. Burian and J. Auleytner: to be published.
6) M.J. Aubin, A. Rambo, J.-C. Portal, C. Houlbert, S. Askénazy and P.R. Wallace: Proc. 3rd Int. Conf. Physics of Narrow-Gap Semiconductors, Warsaw 1977, Polish Sci. Publishers (1978) 312.
7) W. Zdanowicz, L. Zdanowicz, J.-C. Portal and S. Askénazy, Thin Solid Films 61 (1979) 41.
8) S. Kivelson and C.D. Gelatt: Phys. Rev. B19, 10 (1979) 5160.