Quantum Transport and Pressure-induced Superconductivity in the 3D Dirac Semimetal Cd_3As_2

L. P. He[1], X. C. Hong[1], Y. T. Jia[2], S. J. Zhang[2], J. K. Dong[1], J. Pan[1], Z. Zhang[1], J. Zhang[1], C. Q. Jin[2*] and S. Y. Li[1**]

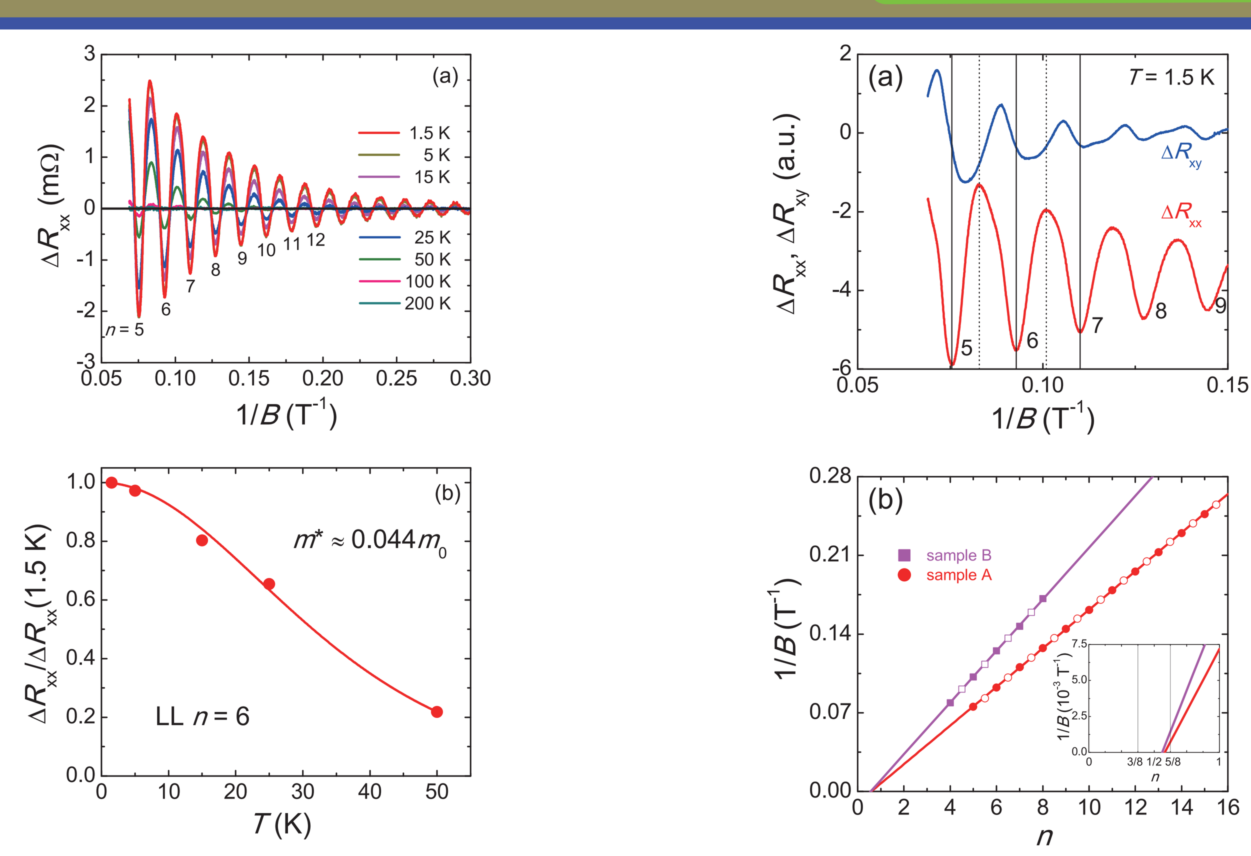
[1]Department of Physics, and Laboratory of Advanced Materials, State Key Laboratory of Surface Physics, Fudan University, Shanghai 200433, China

[2]Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Abstract

We report the quantum transport properties of Cd_3As_2 single crystals in a magnetic field. A large linear quantum magnetoresistance is observed near room temperature. With decreasing temperature, the Shubnikov—de Haas oscillations appear in both the longitudinal resistance R_{xx} and the transverse Hall resistance R_{xy}. From the strong oscillatory component ΔR_{xx}, a linear dependence of the Landau index n on 1/B is obtained, and it gives an n-axis intercept between 1/2 and 5/8. This clearly reveals a nontrivial π Berry's phase, which is a distinguished feature of Dirac fermions. And the resistance of Cd_3As_2 under pressure up to 50.9 GPa was also measured. Surprisingly, superconductivity with $T_c \approx 2.0$ K emerges at 8.5 GPa. The T_c keeps increasing to about 4.0 K at 21.3 GPa, then shows an anomalous nearly constant pressure dependence up to the highest pressure 50.9 GPa. Our observation of superconductivity in pressurized three-dimensional Dirac semimetal Cd_3As_2 provides an interesting candidate for topological superconductor.

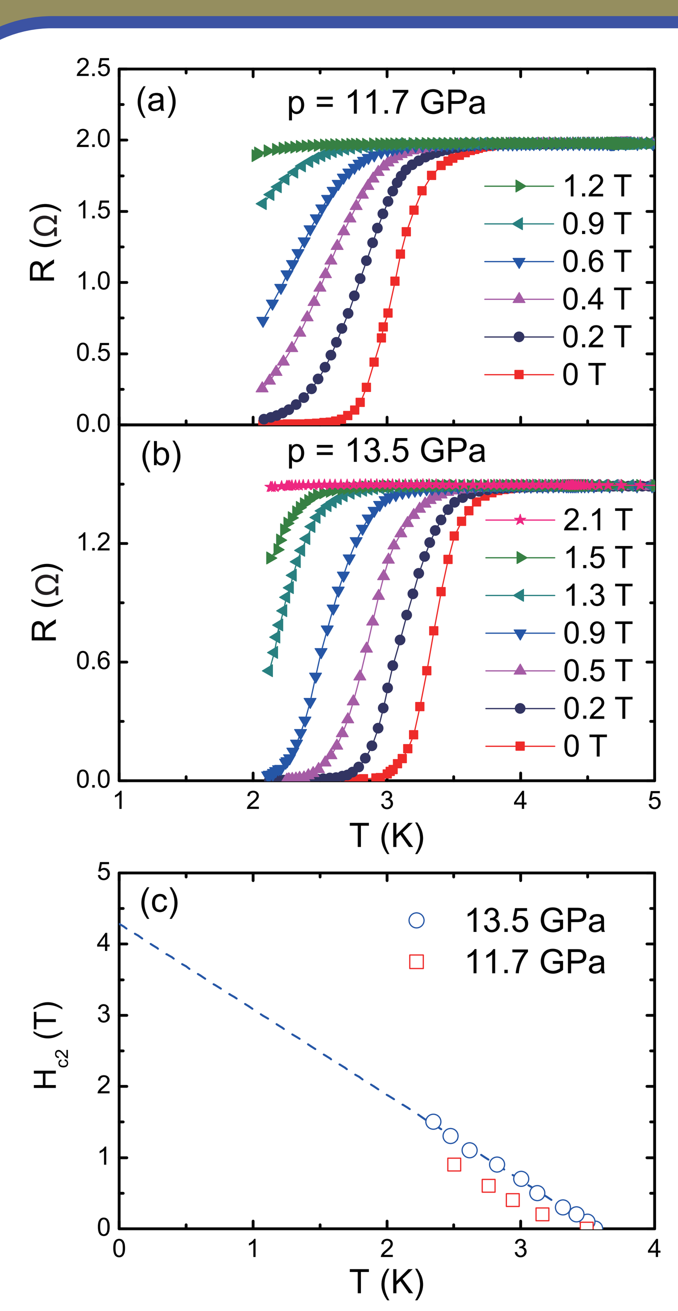
Berry's Phase

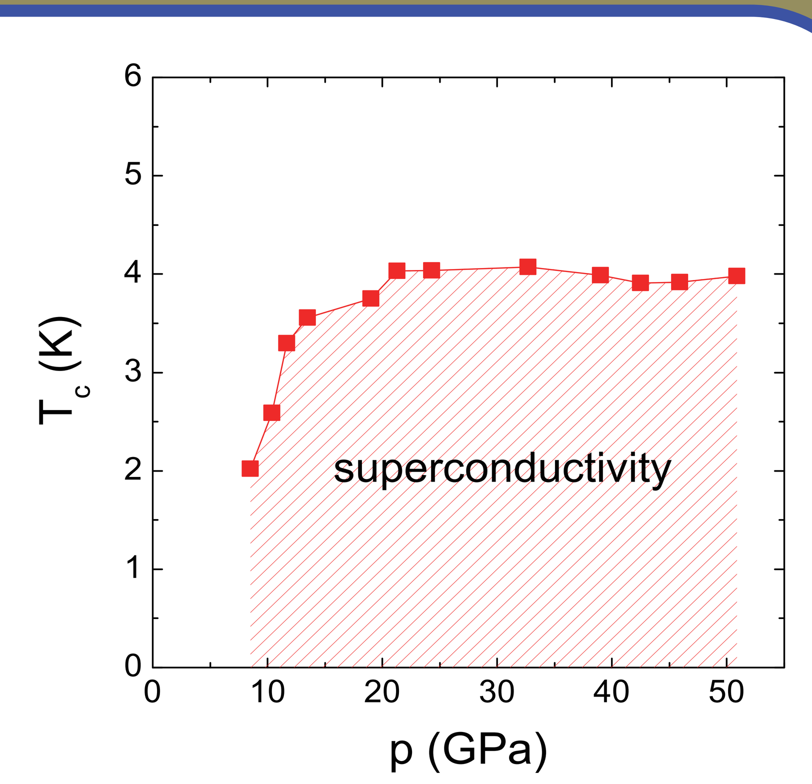


Left: (a) The oscillatory component ΔR_{xx}, extracted from R_{xx} by subtracting a smooth background. (b) The temperature dependence of the relative amplitude of ΔR_{xx} for the 6th Landau level. The solid line is a fit to the LK formula, which gives $m^* \approx 0.044m_0$ and $v_F \approx 1.1 \times 10^6$ m/s.

Right: (a) The high-field oscillatory components ΔR_{xx} and ΔR_{xy} at 1.5 K. The ΔR_{xy} oscillations are phase shifted approximately by 90°. (b) Landau index n plotted against 1/B. The closed circles denote the integer index (ΔR_{xx} valley), and the open circles indicate the half integer index (ΔR_{xx} peak). The index plot can be linearly fitted, giving the intercept 0.58 ± 0.01. The measurements of another single crystal labeled as sample B give a similar intercept 0.56 ± 0.03, which is strong evidence for a nontrivial π Berry's phase of 3D Dirac fermions in Cd_3As_2 [1,2,3].

H_{c2} and Phase Diagram

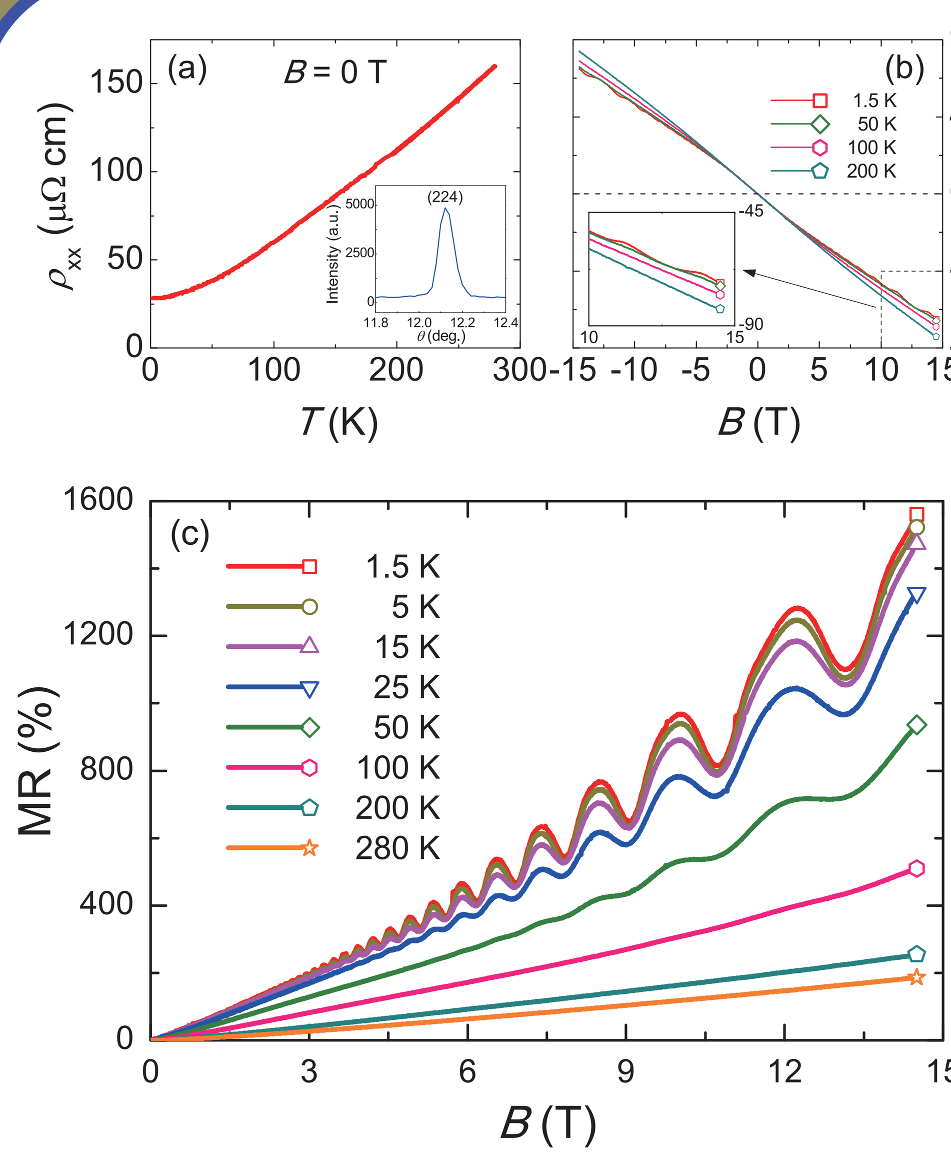


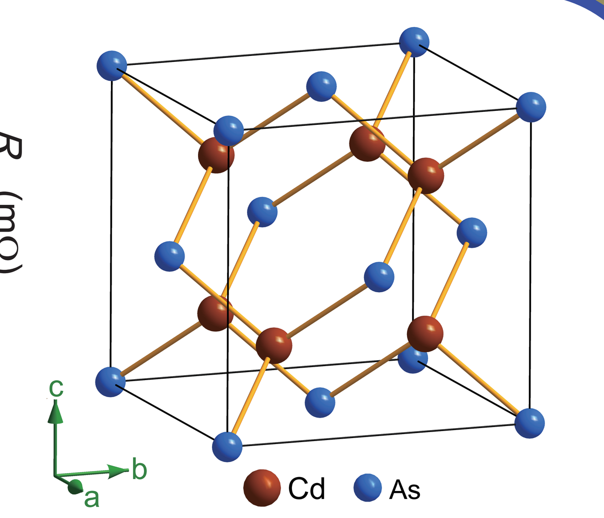


Left: The superconducting transition of the Cd_3As_2 single crystal at (a) 11.7 GPa and (b) 13.5 GPa in magnetic fields applied perpendicular to the (112) plane. (c) Temperature dependence of the upper critical field H_{c2}. The dashed line is a linear fit to the data, which points to $H_{c2}(0) \approx 4.29$ T for 13.5 GPa.

Right: Phase diagram of Cd_3As_2 showing the superconducting transition temperature T_c as a function of pressure. This phase diagram is similar to that of 3D topological insulator Bi_2Se_3 [4].

Magnetoresistance





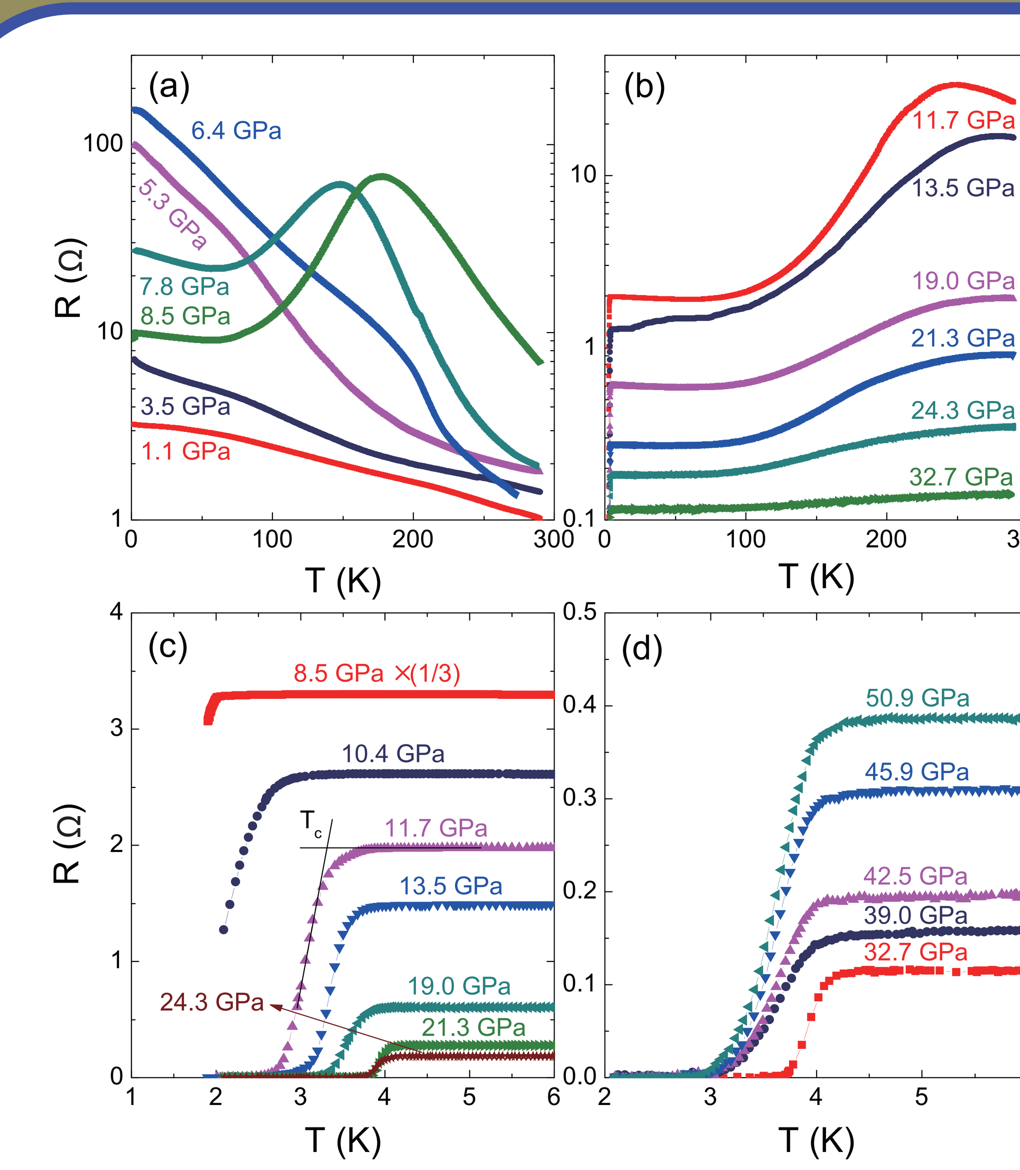
Crystal structure of Cd_3As_2

(a) The longitudinal resistivity of a Cd_3As_2 single crystal in zero magnetic field, with current in the (112) plane.

(b) The Hall resistance R_{xy} at 200, 100, 50, and 1.5 K. There are clear oscillations of R_{xy} at 1.5 K, as seen in the inset.

(c) The Shubinikov—de Haas oscillations of longitudinal magnetoresistance (MR) at various temperatures, with the field perpendicular to the (112) plane. At 1.5 K, the oscillations appear at a field as low as 2 T, reflecting the high mobility of charge carriers in Cd_3As_2.

Superconductivty



The temperature dependence of resistance for Cd_3As_2 single crystal under various pressures.

(a) and (b): the resistance from 1.8 to 300 K. Below 6.4 GPa, the resistance increases with applying pressure and its temperature dependence changes from metallic to inslating behavior. However, upon further increaing pressure, the resistance at low temperature decreases with pressure.

(c) and (d): low-temperature resistance showing the superconducting transition. The superconductivity appears at p = 8.5 GPa with $T_c \approx 2.0$ K. The T_c is defined as on the curve of p = 11.7 GPa. The T_c increases to about 4.0 K at 21.3 GPa, then persists to the highest pressure 50.9 GPa.

References

[1] Z. K. Liu, J. Juan *et al.*, Nat. Mater. **13**, 677 (2014).

[2] Y. B. Zhang, Y. W. Tan, H. L. Stormer, and P. Kim, Nature (London) **438**, 201 (2005).

[3] H. Murakawa *et al.*, Science **342**, 1490 (2013).

[4] K. Kirshenbaum *et al.*, Phys. Rev. Lett. **111**, 087001 (2013).

Summary

In summary, we have performed bulk transport measurements on single crystals of the proposed 3D Dirac semimetal Cd_3As_2. A large linear quantum magnetoresistance is observed nearroom temperature. By analyzing the Shubnikov—de Haas oscillations of longitudinal resistance at low temperature, a nontrivial π Berry's phase with a small phase shift is obtained, which provides bulk quantum transport evidence for the existence of a 3D Dirac semimetal phase in Cd_3As_2. We have done resistance measurements on the 3D Dirac semimetal Cd_3As_2 single crystals under pressures up to 50.9 GPa. Below 6.4 GPa, the resistance behavior becomes more and more insulating with increasing pressure, however it changes back to metallic again at higher pressures. Superconductivity emerges at 8.5 GPa. The T_c increases from 2.0 K at 8.5 GPa to 4.0 K at 21.3 GPa, then it shows an anomalous constant pressure dependence up to the highest pressure measured.

Phys. Rev. Lett. 113, 246402 (Editors' Suggestion) (2014)
arXiv:1502.02509 (2015)