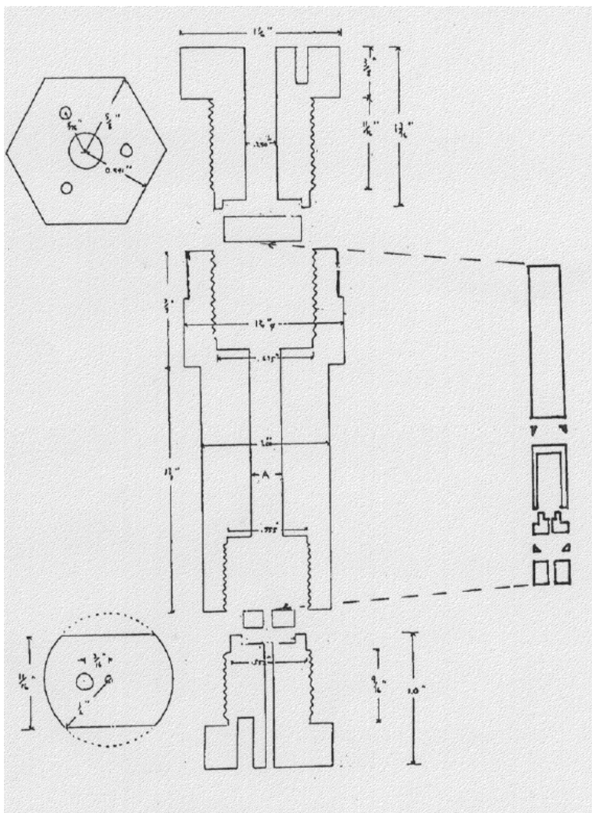
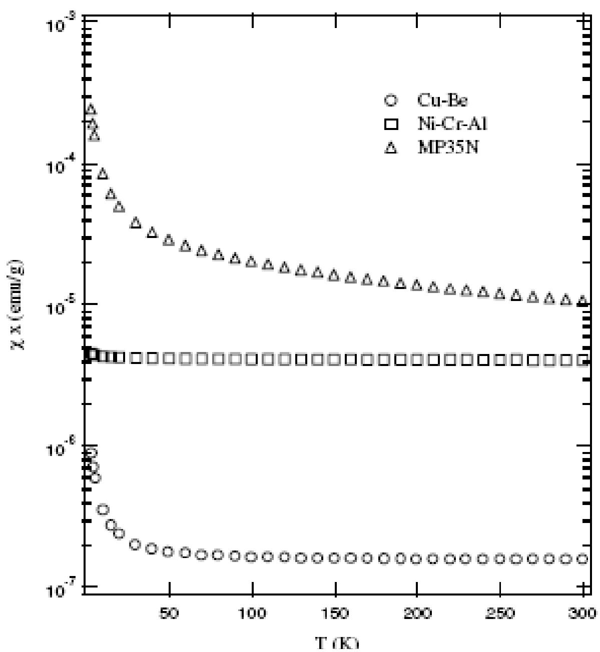
High Pressure Transport Methods

Matter at extreme conditions – particularly developed in Europe, Japan. See for example http://www.issp.u-tokyo.ac.jp/labs/extreme/index-e.html

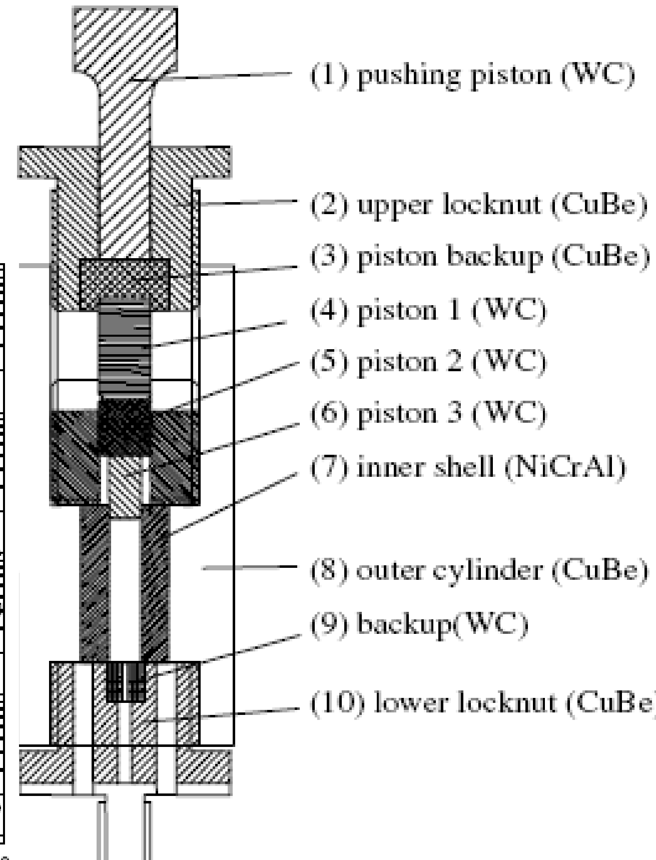
Piston cylinder type high pressure cells for resistivity measurements.



Cu-Be pressure cell for low T transport and magnetization studies (MST-10 LANL)



Introduction to thermal and transport techniques



“Russian alloy” hybrid pressure cell at ISSP University of Tokyo, Japan
J. Phys. Cond. Matter 14, 11291 (2002)

Sample Preparation for High Pressure Resistivity

In the usual arrangement inside of Cu-Be pressure cell hosts one sample with 4 pairs of leads for four probe resistivity measurement and a piece of superconducting metal (Pb, Sn) which is used as a manometer (since dT_C/dP is known). The T_C of manometer is measaured by winding pick up coil for ac susceptibility measurement, and applying excitation ac field outside the pressure cell.

However, it is also possible to measure simultaneously resistivity and ac susceptibility of a sample in the pressure cell.

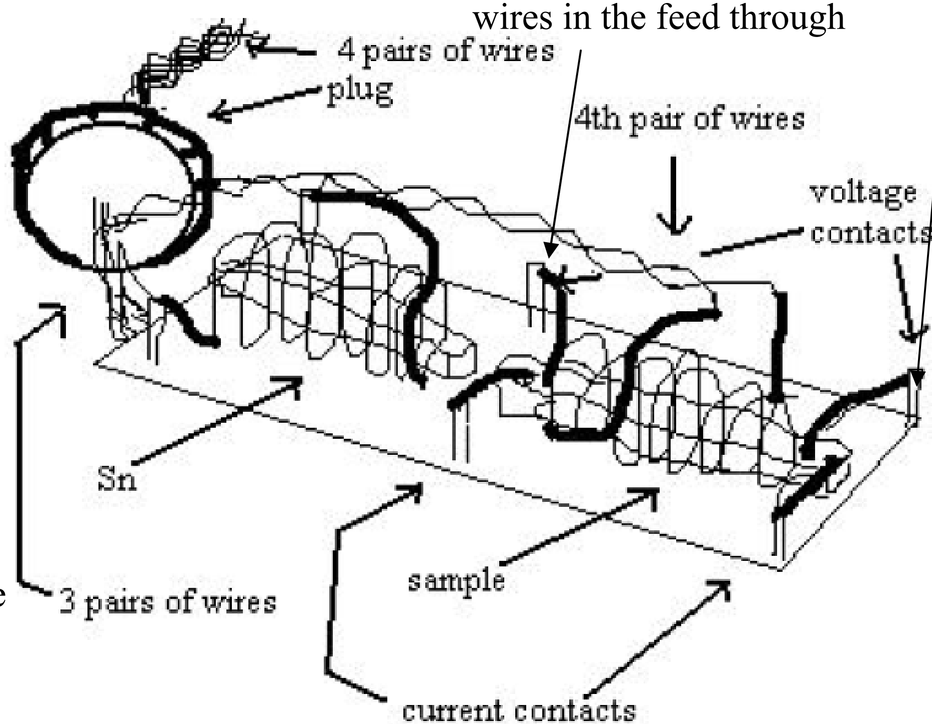
Two pick up coils inside a teflon cup of the pressure cell are mounted: one for sample and one for manometer. manometer is cut in the same shape as the sample

Between the voltage contacts pick up coil is placed. Manometer has twofold purpose, pressure determination, a caliper of the superconducting volume fraction of the sample.

Three pairs of wires for current, voltage and Sn pick up coil are Glued at the bottom of the plastic platform and the contacts are moved up to the upper part of platform through previously prepared platform holes. The fourth pair of wires for the sample pick up coil is placed on the top of the sample and fixed with a small quantity of the glue.

As a pressure transmitting medium, Flourinert-75 is used.

Pressure is applied at room T.



Sample environment for simultaneous resistivity, ac susceptibility in piston cylinder pressure cell

Quantum Oscillations in High Magnetic Fields 1

Movement of conduction electrons in B is quantized (Landau): $\varepsilon(n, p_B) = (n+1/2)\hbar\omega_c + p_B^2/2m_e$

Magnetic field confines electrons to orbits of radius r_B=p/eB in the plane ⊥ B.

$\omega_c = eB/m_e = 2\pi eB/(\partial S/\partial\varepsilon)_{pB}$

p_B=Component P↑↑B

Circumsference of this orbit is n·wavelength → discrete set of energy levels – in reciprocal space states are on coaxial tubes with crossection area perpendicular to B:

$$S_n(n, p_B) = (n+1/2)2\pi\hbar eB$$

At T=0 e^- fill up states up to ε_F. With the increase of B, number of states on the largest Landau tube which is still inside the FS decreases and = 0 when tube touches extreme crosssection of the Fermi surface S_{extr}. As B increases Landau tubes cross S_{extr} with period:

$$\Delta\left(\frac{1}{B}\right) = \frac{2\pi e\hbar}{S_{extr}}$$

→ periodic variation in the F, ρ(ε), oscillations in M, σ, β, C_p, …From period of oscillations we can determine S_{extr}. **Most frequently used are dHvA for $M\sim(\partial F/\partial B)_T$ and SdH σ (since $\sigma\sim\rho(\varepsilon_F)\sim(m_cB/S_{extr})^2\cdot(\partial M/\partial B)$)**

Oscillatory part of M along B is given by Lifshitz-Kosevich formula:

Damping factors due to T, scattring (D) and Zeeman splitting (S)

$$M_{osc} = -\sum_{r=1}^{\infty}\frac{1}{r^{3/2}}M_r \sin\left[2\pi r\left(\frac{F}{B}-\frac{1}{2}\right)\pm\frac{\pi}{4}\right]; F = \frac{S_{extr}}{2\pi e\hbar}; Mr = \left(\frac{e}{2\pi\hbar}\right)^{3/2}\frac{S_{extr}B^{1/2}}{\pi^2 m_c |S''|_{extr}^{1/2}} R_T(r)R_D(r)R_S(r)$$

Sum of all harmonics, in practice r=1 is enough

$S'' = (\partial^2 S/\partial\varepsilon^2)_{pB}$

$$\sigma_{osc} = \sigma_0\sum_{r=1}^{\infty}\frac{1}{r^{1/2}}a_r \cos\left[2\pi\left(\frac{F}{B}-\frac{1}{2}\right)\pm\frac{\pi}{4}\right]; a_r \sim \frac{m_c B^{1/2}}{(S'')_{extr}^2}R_T(r)R_D(r)R_S(r)$$

For crosssection area S minimum and maximum

D. Schoenberg: *Magnetic oscillations in Metals*, Cambridge University Press (1984)
See also Chem. Rev. 104, 5737 (2004)

Quantum Oscillations in High Magnetic Fields 2

Take 1st harmonic, assume S_{max}-S_{min}~0 and F=(S_{max}-S_{min})/4πeħ, ΔF=ΔS/2πeħ we get M_{osc}:

$$M_{osc} \sim 2M_1 \sin\left[2\pi\left(\frac{F}{B}-\frac{1}{2}\right)\right]\cos\left(2\pi\frac{\Delta F}{2B}-\frac{\pi}{4}\right)$$

→ By extracting fundamental frequencies F of oscillations we can estimate average crossection area of the FS. We can also trace oscillations as a function of B orientation (**think single crystals**).

K=const~14.7T/K, **$\mu=m_c/m_e$**

→ T damping factor of amplitude R_T - due to T smearing of Fermi function: $R_T(r) = \dfrac{Kr\mu(T/B)}{\sinh(Kr\mu T/B)}$

For large arguments of the function, sinhx ~ exp(x)/2 → $R_T(r) \sim \dfrac{T}{B}e^{-(Kr\mu T/B)}$

We can get μ from the slope ***ln(M_r(t) or ln(a_r(t) vs T → mass ratio can tell us about interactions (e^- - e^-, e^- - ph,..)in the system when compared with bare band mass***

→ Scattering damping factor of amplitude R_D - due to broadening of Landau levels (clean crystals with long mean free path are important):

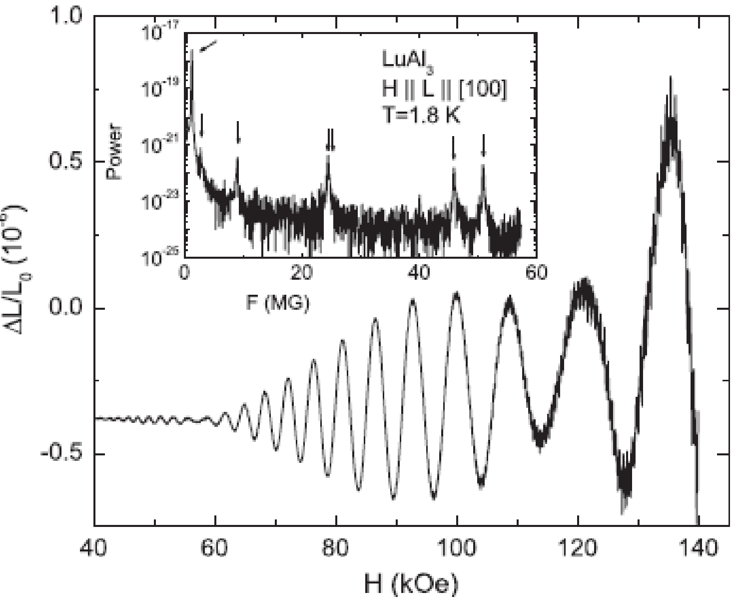
$$R_D(r) = e^{-\pi r/\omega_c\tau} = e^{-Kr\mu T_D/B};\ T_D = \hbar/(2\pi k_B\tau)$$

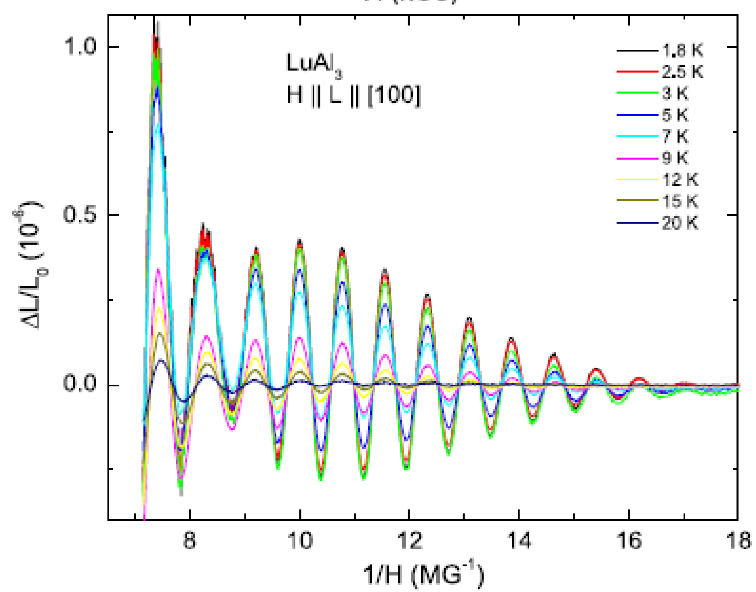
Dingle T → Once we know μ, we can get T_D and relaxation time from the field dependence of the amplitude

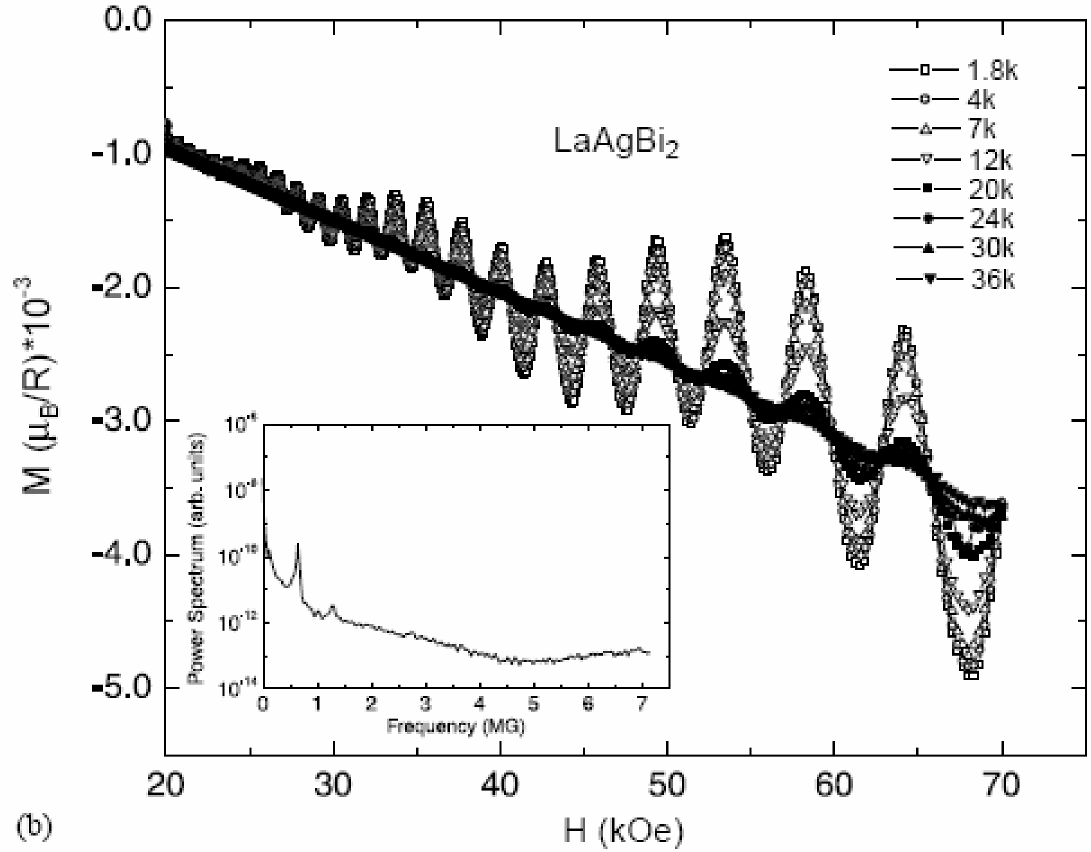
→ Zeman splitting of Landau subbands Δε~gμ_BB. For free e^- g=2 so Δε~ħω_c and they contribute in phase to oscillations. In real metal Δε≠ħω_c so there is a phase shift due to contributions from subbands with opposite spin and reduction of amplitude by R_S(r)~cos(πrgμ/2) so we can get g (renormalized by interactions)

Sov. Physics JETP 2, 636 (1956)

Quantum Oscillations in Laboratory Fields…







J. Phys. Cond. Matt. 20, 025220 (2008)

J. Magn. Magn. Mater. 261, 210 (2003)

…or in High Fields

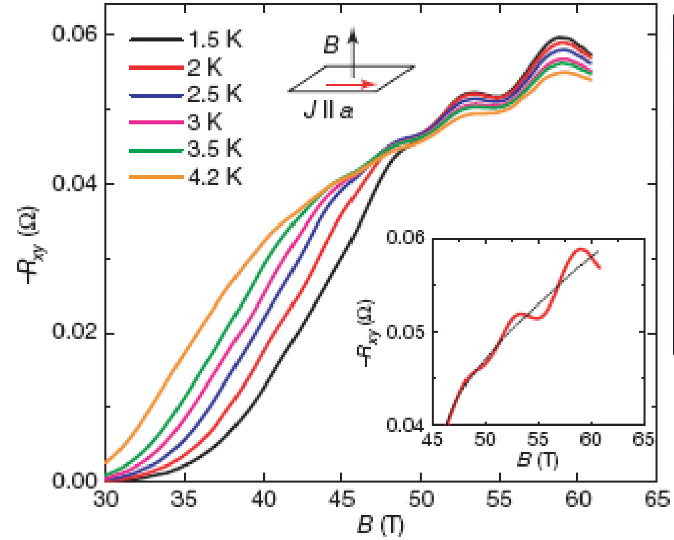
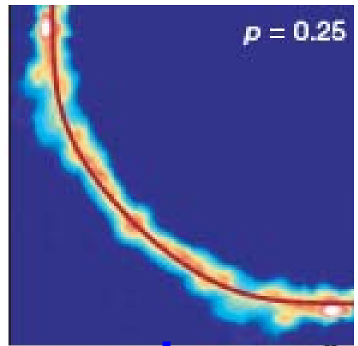
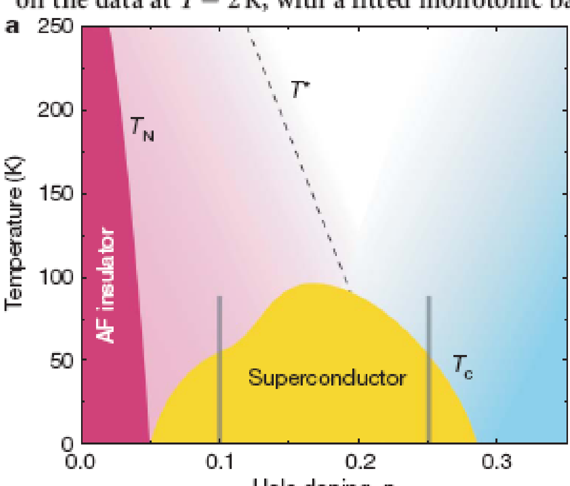
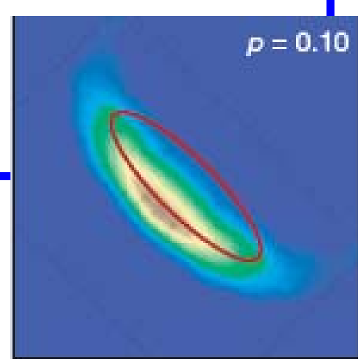
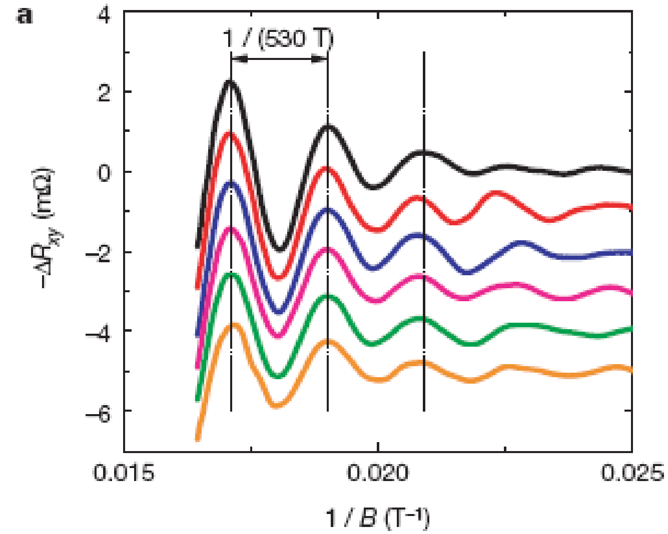


Figure 2 | Hall resistance of $YBa_2Cu_3O_{6.5}$. R_{xy} as a function of magnetic field B, for sample A, at different temperatures between 1.5 and 4.2 K. The field is applied normal to the CuO_2 planes ($B||c$) and the current is along the a axis of the orthorhombic crystal structure ($J||a$). The inset shows a zoom on the data at $T = 2$ K, with a fitted monotonic background (dashed line).









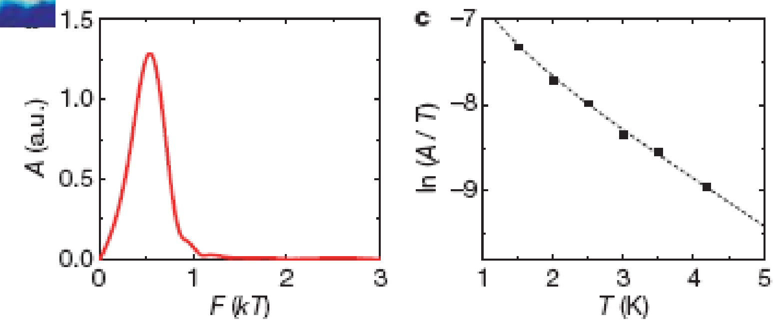


Figure 3 | Quantum oscillations in YBCO. a, Oscillatory part of the Hall resistance, obtained by subtracting the monotonic background (shown in the inset of Fig. 2 for $T = 2$ K), as a function of inverse magnetic field, $1/B$. The background at each temperature is given in Supplementary Fig. 2. **b**, Power spectrum (Fourier transform) of the oscillatory part for the $T = 2$ K isotherm, revealing a single frequency at $F = (530 \pm 20)$ T, which corresponds to a k-space area $A_k = 5.1$ nm^{-2}, from the Onsager relation $F = (\Phi_0/2\pi^2)A_k$. Note that the uncertainty of 4% on F is not given by the width of the peak (a consequence of the small number of oscillations), but by the accuracy with which the position of successive maxima in **a** can be determined. **c**, Temperature dependence of the oscillation amplitude A, plotted as $\ln(A/T)$ versus T. The fit is to the standard Lifshitz–Kosevich formula, whereby $A/T = [\sinh(am^*T/B)]^{-1}$, which yields a cyclotron mass $m^* = (1.9 \pm 0.1)m_0$, where m_0 is the free electron mass.

Nature 447, 565 (2007)