Quantum oscillations in the specific heat of graphite reveal hidden physics in Kittel

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We show that the electronic specific heat C_{el} in natural graphite exhibits a double-peak structure when a *single* spin Landau level crosses the Fermi energy. Crucially, such a double peak is not observed in other thermodynamic probes. At lower temperatures, the splitting decreases, and vanishes as $T \to 0$. Intriguingly, the double-peak structure is predicted by text book theory, $C_{el}/T = k_B^2 \int D(E)(-x^2 df/dx)dx$ where $f(x) = 1/(1+e^x)$, $x = E/k_BT$. The specific heat depends on the convolution of the Landau level density of states $D(E)$ and a kernel term $-x^2 df/dx$ which involves the first derivative of the Fermi-Dirac distribution function. The usual approximation (see e.g. Kittel), removing D(E) from the integral to obtain the well know formula $C_{el} = \frac{1}{3}\pi^2 D(E_F)k_B^2 T$, suppresses the double-peak structure which originates from the temperature dependent splitting of the double maxima in the kernel term. The calculated and predicted C_{el}/T are in excellent agreement, notably they reveal the highly asymmetric DOS of 3D Landau levels due to the van Hove singularity. The kernel term represents a spectroscopic tuning fork of width $4.8k_BT$ which can be tuned at will to resonance. Using a coincidence method, the double-peak structure can be used to accurately determine the g-factors of quantum materials. More generally, the tuning fork can be used to reveal any peak in the fermionic density of states which crosses the Fermi energy, such as for example Lifshitz transitions in heavy-fermion compounds.

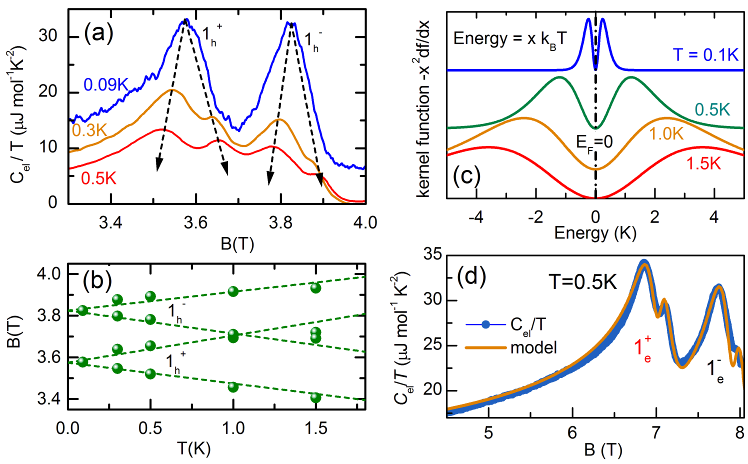

Figure 1: *(a) C_{el}/T versus B where the 1h spin Landau levels cross E_F in natural graphite. (b) Position of the double-peak structure versus temperature. (c) The kernel term plotted versus $E = xk_BT$. Maxima occur at x= ±2.4 (d) Measured and calculated C_{el}/T close to where the 1e spin Landau levels cross E_F.*

[1] Yang et al., Nature Communications **14**, 7006 (2023).