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Phase Transitions of Dirac Electrons in Bismuth[1]

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The Fermi Surface (FS) in elemental bismuth consists of 3 electron ellipsoids and one hole ellipsoid [1]. The accidental coincidence of the hole and electron caliper areas when the field **H** is aligned with the trigonal axis **Z** has long stymied analyses of the quantum oscillations. Because of current strong interest in how electrons with Dirac dispersion behave in intense fields, we have renewed attack on this problem [2] using high-resolution torque magnetometry in fields up to 31 T and at temperatures T down to 300 mK. When **H** is tilted with respect to **Z** by a slight angle θ, the torque $\vec{\tau}$ on the sample derived from the 3 electron ellipsoids dominates the torque from the hole FS, allowing the Landau Level crossings of the Dirac electron to be resolved. By measuring the curves of $\vec{\tau}$ vs. H at 19 values of θ straddling the trigonal axes, we completely resolve the Landau Levels of the Dirac electrons. A new result is the detection of jumps in the transverse magnetization when H exceeds the quantum limit of the electron pockets. By tracing the jumps in the plane of H vs. θ, we uncover a region in which the Dirac electrons enter a new ground state. Within this cone-shaped region, Landau Level anomalies are severely suppressed. We interpret the state as one in which the 3-fold valley degeneracy of the Dirac gas is lifted to form a many-body state. The unusual nature of the magnetization within this region will be described.

[1] M. H. Cohen and E. I. Blount, Phil. Mag. **5**, 115 (1960).
[2] Lu Li *et al.*, Science **321**, 547 (2008).

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