Orbital Physics: Colossal Magnetoresistance and Quantum Oscillations in the Mott System

Ca$_3$Ru$_2$O$_7$
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Ca$_3$Ru$_2$O$_7$ features a Mott transition, colossal magnetoresistance and quantum oscillations. Ca$_3$Ru$_2$O$_7$ shows strikingly different behavior when the field is applied along the different crystal axes. A ferromagnetic (FM) state with full spin polarization is achieved for $B||a$-axis, but colossal magnetoresistance is realized only for $B||b$-axis by avoiding the ferromagnetic state. For $B||c$-axis, Shubnikov-de Haas oscillations are observed and followed by a less resistive state than for $B||a$. Hence, in contrast to standard colossal magnetoresistive materials, the FM phase is the least favorable for electron hopping. In addition, for $B$ rotating within the $ac$-plane, slow and strong Shubnikov-de Haas (SdH) oscillations periodic in $1/B$ are observed for $T \leq 1.5$ K in the presence of metamagnetism. These oscillations are highly angular dependent and intimately correlated with the spin-polarization of the ferromagnetic state. For $B||[110]$, oscillations are also observed but periodic in $B$ (rather than $1/B$) which persist up to $15$ K. While the SdH oscillations are a manifestation of the presence of small Fermi surface (FS) pockets in the Mott-like system, the B-periodic oscillations, an exotic quantum phenomenon, may be a result of anomalous coupling of the magnetic field to the $t_{2g}$-orbitals that makes the extremal cross-section of the FS field-dependent.