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Fractional quantum Hall effect in AlAs quantum wells: Role of valley degree of freedom

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When interacting two-dimensional electrons are placed in a large perpendicular magnetic field, to minimize their energy, they capture an even number of flux quanta and create new particles called composite fermions (CFs). These complex electron-flux-bound states offer an elegant explanation for the fractional quantum Hall effect. Thanks to the flux attachment, the effective field vanishes at half-filled Landau levels ($\nu = 1/2$ and $3/2$) and CFs exhibit Fermi-liquid-like properties, similar to their zero-field electron counterparts. Here, we study a two-dimensional electron system in AlAs quantum wells where the electrons occupy two conduction band valleys with anisotropic Fermi contours and strain-tunable occupation. We address a fundamental question whether the anisotropy of the electron effective mass and Fermi surface is transferred to the CFs formed around filling factors $\nu = 1/2$ and $3/2$. Similar to their electron counter parts, CFs also exhibit anisotropic transport, suggesting an anisotropy of CF effective mass and Fermi surface. We also study quantum Hall ferromagnetism for fractional quantum Hall states formed at $\nu = 1/3$ and $5/3$ as a function of valley splitting. Within the framework of the CF theory, electronic fractional filling factors $\nu = 1/3$ and $5/3$ are equivalent to the integer filling factor $p = 1$ of CFs. Reminiscent of the quantum Hall ferromagnetism observed at $\nu = 1$, we report persistent fractional quantum Hall states at filling factors $\nu = 1/3$ and $5/3$ when the two valleys are degenerate. However, the comparison of the energy gaps measured at $\nu = 1/3$ and $5/3$ to the available theory developed for single-valley, two-spin systems reveals that the gaps and their rates of rise with strain are much smaller than predicted.

[1] "Transference of Transport Anisotropy to Composite Fermions," T. Gokmen, M. Padmanabhan, and M. Shayegan, *Nature Physics* **6**, 621-624 (2010).

[2] 'Ferromagnetic Fractional Quantum Hall States in a Valley-Degenerate Two-Dimensional Electron System," M. Padmanabhan, T. Gokmen, and M. Shayegan, *Phys. Rev. Lett.* **104**, 016805 (2010).