Evolution of the Lowest Extended State in a Vanishing Effective Magnetic Field in the Fractional Quantum Hall Regime

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The fractional quantum Hall effect (FQHE) observed in high-quality two-dimensional (2D) electron systems in the low-temperature, high magnetic field regime, arises from strong electron-electron interactions. In the elegant composite fermion (CF) picture [1] the FQHE can be understood as a manifestation of the interger quantum Hall effect of weakly interacting CFs. It has been shown that at a Landau level filling factor ν=1/2, a 2D electron system can be mathematically transformed into a CF system interacting with a Chern-Simons gange field. At ν=1/2, the average of this Chern-Simons gange field cancels the external magnetic field B_{ext} so that the effective magnetic field B_{eff} acting on the CFs is zero. Away from ν=1/2, the CFs experience a net effective magnetic field $B_{eff} = (1-2\nu)B_{ext}$.

The existence of extended state is an essential ingredient in the theory of the quantum Hall effect. It is now well established that the energy of an extended state in a quantum Hall system is centred around its Landau levels $E_N = (N+1/2)\hbar\omega_c$ in the high-magnetic-field regime. Experimentally the evolution of the peaks in the longitudinal conductivity σ_{xx} (or the longitudinal resistivity ρ_{xx}) can be used to map out the extended states in the density *n* (or energy) – magnetic field plane. In the seminal work of Glozman, Johnson and Jiang [2], there is compelling evidence that the lowest extended state floats up above the Fermi level as the magnetic field approaches zero. In this work, we present the first study of the evolution of the lowest extended state in a *vanishing* effective magnetic field in the fractional quantum Hall regime. Within the CF picture, for the lowest extended state we can derive the relation $\frac{n}{B_{eff}} = \frac{3}{2}\frac{e}{h}$ from

$$E_F^{CF} = \frac{\hbar^2 k_F{}^2}{2m_{CF}^*} = (N+\frac{1}{2})\hbar\frac{eB_{eff}}{m_{CF}^*} \quad , \tag{1}$$

where $k_F = \sqrt{4\pi n}$ for a CF and N=1.

We perform low-temperature measurements on a high-quality gated GaAs electron system. By changing the applied gate voltage, we are able to study the evolution of the extended states as a function of electron density. Our results show that the evolution of the lowest extended state exhibits a linear dependence on B in the *n*-B diagram, as shown in Fig. 1. Within the composite fermion picture, the evolution shows a good linear dependence on the effective magnetic field B_{eff}, as shown in Fig. 2. The slope is close to the theoretical value ($\frac{3}{2}\frac{e}{h}$). Due to the cancellation of m_{CF}^* in Eq. (1), the conventional Landau fan diagram is valid in the composite fermion picture, despite possible divergence and carrier-density dependence of the composite fermion effective mass at ν=1/2.

References:

[1] J. K. Jain, Phys. Rev. Lett. 63, 199 (1989).

[2] I. Glozman, C. E. Johnson and H. W. Jiang, Phys. Rev. Lett. 74, 594 (1995).

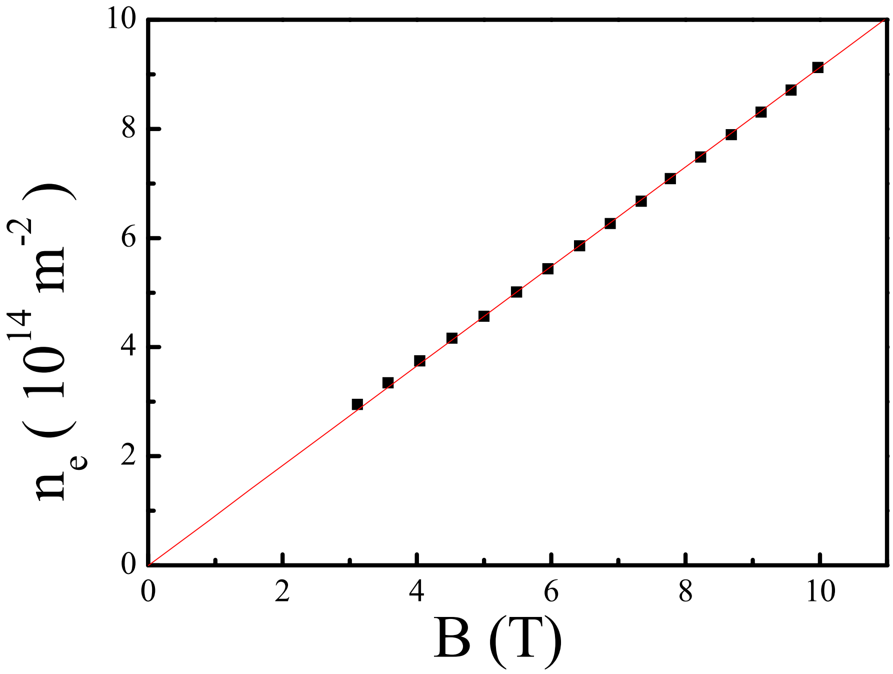

Figure 1. The lowest extended state shows a linear dependence on B in the density-magnetic field plane.

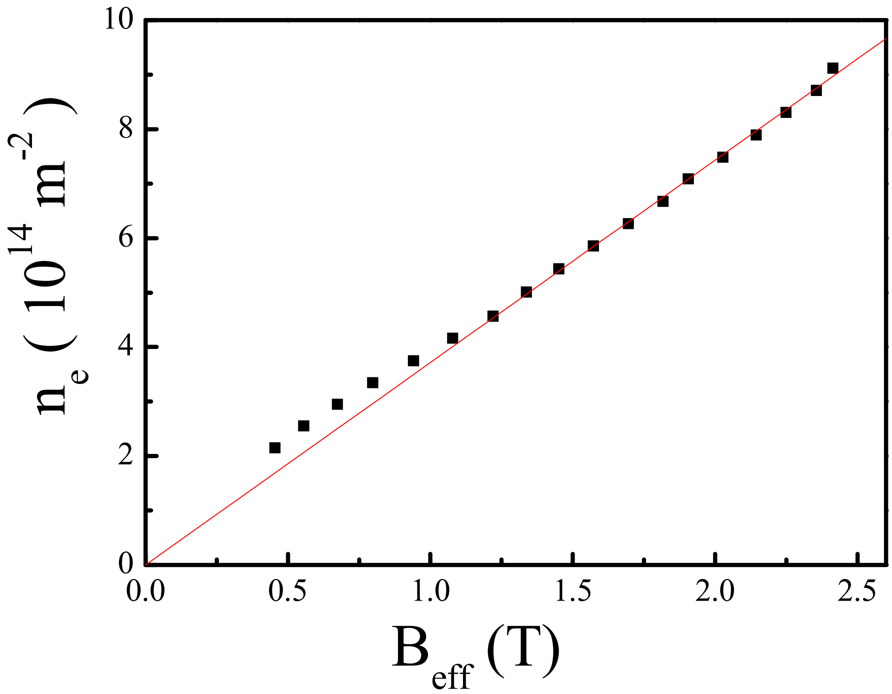

Figure 2. A good linear dependence on the effective magnetic field B_{eff} in the density-effective magnetic field plane. The slope is 3.715×10^{14}, close to the theoretical value ($\frac{3}{2}\frac{e}{h} = 3.622\times10^{14}$).