# From localization to Landau quantization in a two-dimensional GaAs electron gas containing self-assembled InAs quantum dots

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Recently there has been a great renewal of interest in magnetic-field-induced transitions in the integer quantum Hall effects. According to the scaling theory of localization, in zero magnetic field there are only localized states in a noninteracting two-dimensional (2D) system at low temperatures. In the presence of a strong perpendicular magnetic field the Landau quantization becomes important, causing the formation of Landau levels in a 2D system. The picture of extended states at the Landau level centers and localized states between Landau levels provides a simple explanation for the quantum Hall effect. The evolution of electronic states from being extended at a strong magnetic field $B$ to being localized at $B = 0$ was first explained by Laughlin and Khmelnitskii. It is argued that to be consistent with the scaling theory, the extended states could float up in energy as the magnetic field is reduced. An alternative to this floating-up picture is that the extended states could be destroyed by decreasing the magnetic field or increasing the disorder. To date, an interesting but unsettled issue is whether the observed direct transitions from an insulating state to a high Landau level filling factor $\nu \geq 3$ are genuine quantum phase transitions. Experimental and numerical studies show that such transitions are quantum phase transitions. On the other hand, it is argued that that such low-field transition is not a phase transition, but can be identified as a crossover from localization to a strong reduction of the conductivity when Landau quantization becomes dominant. Although in the vicinity of a quantum phase transition, it is expected that scaling behavior should occur, inter-Landau level mixing of opposite chirality might affect the scaling behavior.

In this paper, we report magnetotransport measurements on a gated GaAs electron system containing self-assembled InAs quantum dots. Our results fall into three categories. (i) We show that Shubnikov-de Haas (SdH) oscillations arising from Landau quantization can exist in both the low-field and high-field insulating regimes. At low $B$, SdH oscillations are observed when the 2DEG is in the insulating phase. With increasing $B$, there is an insulator-quantum Hall (I-QH) transition at a well-defined critical magnetic field. These results clearly show that Landau quantization and localization *can* coexist. (ii) By tracing the SdH minima and critical points in $\rho_{xx}$, we are able to construct a "new" phase diagram and from which we show that the critical points of the I-QH transitions *do not* correspond to crossover from localization to Landau quantization. (iii) Scaling behavior was observed on both sides of the critical point in $\rho_{xx}$ and the onset of the SdH oscillations causes deviation from the scaling effect. Our experimental results challenge conventional understanding of Landau quantization and phase transitions in two dimensions, and thus urge further experimental and theoretical studies in these areas.

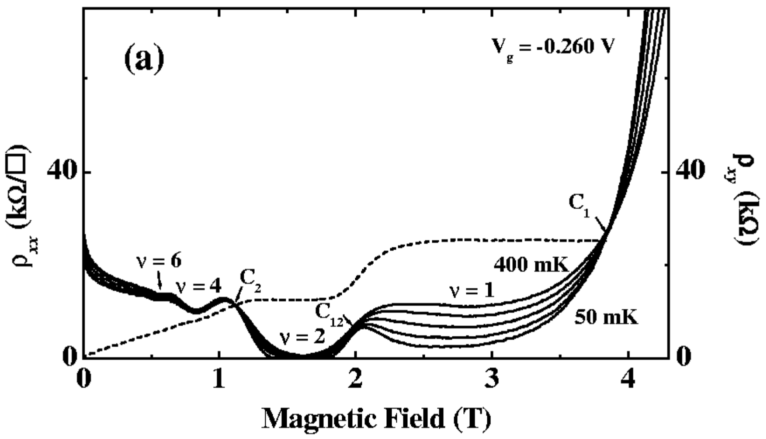


Fig 1. $\rho_{xx}$ as a function of magnetic field at temperatures 50, 140, 220, 300, and 400 mK. The dotted line shows $\rho_{xy}$ at T=300 mK.

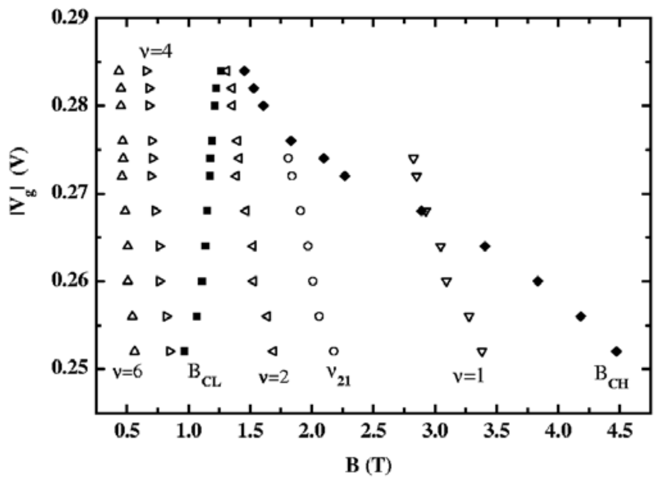


Fig 2. The phase diagram determined from temperature independent points and SdH minima in $\rho_{xx}$ traces. Various transitions are marked: 0-2 (solid squares), 2-0 (solid circles), 2-1 (open circles) and 1-0 (full diamonds). Open triangles represent SdH minima at different filling factor ν=6, 4, 2 and 1, respectively.

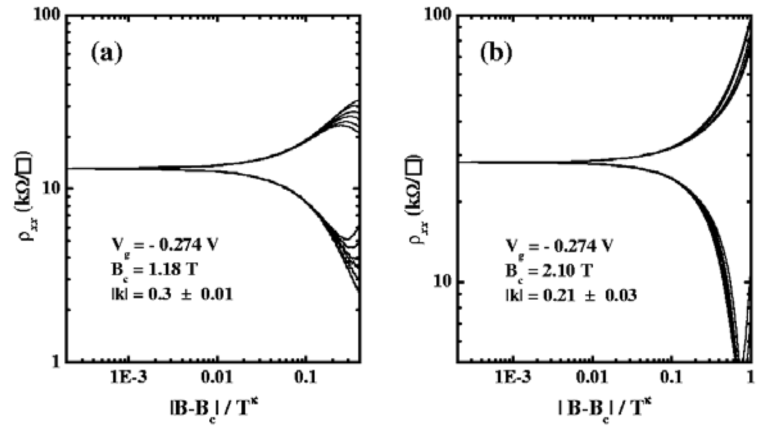


Fig 3. Scaling fits of the magnetoresistivities $\rho_{xx}$ as a function of $|B\text{-}B_c|/T^{\kappa}$ with (a) κ=0.30±0.01 near the low-field transition and (b) κ=0.21±0.03 near the high-field transition.