Influence of a carrier density gradient on the critical behaviour of the quantum Hall effect

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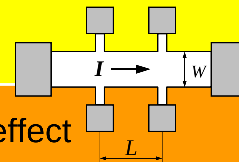
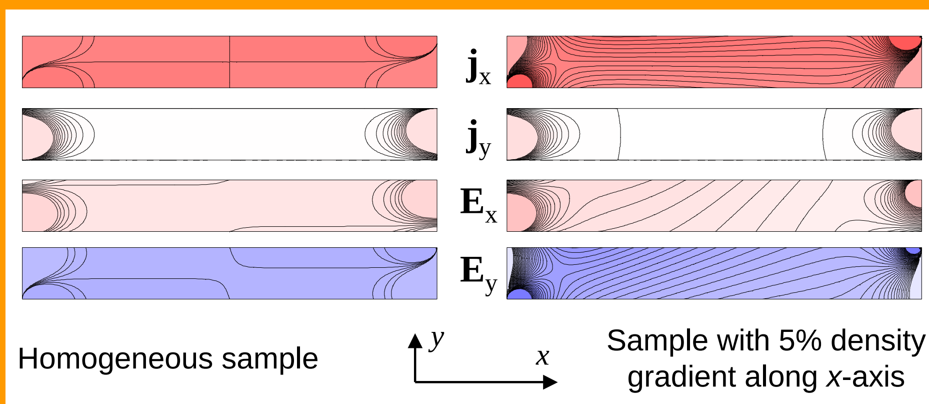
We report numerical simulations for the longitudinal and transverse resistance of a 2DEG in Hall bar geometry. The four-point resistances are evaluated from Maxwell equations using the finite difference method. We assume the components of the local resistivity tensor to show quantum Hall effect and obey scaling behaviour with a universal exponent κ. We then investigate the effect of gradients in the carrier concentration on the scaling behaviour and on the critical exponent extracted from the four-point resistance. We find that simulated magnetotransport data of the plateau-insulator transition are rather robust to inhomogeneities and provide direct access to the value of the critical exponent κ. In contrast, the magnetotransport data at the plateau-plateau transitions are very sensitive to density gradients and the extracted exponents can be significantly smaller than the true κ, in accordance with experiments.



Simulation of the current and electric field distribution in quantum Hall effect

Small number of the lines of constant value indicate homogeneous distribution of the electric field and current density. Distortions at the edges show that the current enters and leaves the sample mainly through the left-bottom and top-right corners.

The results of the numerical simulations coincide with the analytical solution.



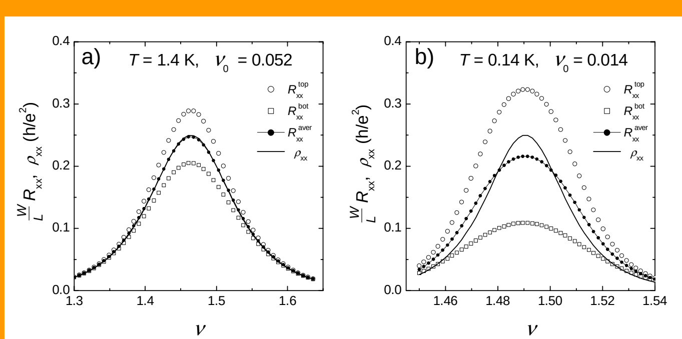
The inhomogeneous problem is essentially non-linear and cannot be solved analytically, except for some special cases. From the simulated distributions of the electric field for each value of the filling factor and temperature the four-point resistance can be calculated.

Large number of lines of constant value indicates significant change of **E** and **j** across the sample.

PP vs PI

Model PI: $\rho_{xy}(\nu,T)=\frac{h}{e^2}$; $\rho_{xx}(\nu,T)=\frac{h}{e^2}\exp\frac{\nu_c-\nu}{\nu_0(T)}$, where $\nu_0(T)=\left(\frac{T}{T_0}\right)^{\kappa}$

Model PP: Landau level addition transformation



The gradient of the carrier density in the x-direction affects the height and width of the peak in $\rho_{xx}(\nu)$. The effect is especially pronounced at low temperatures (b).

Due to the gradient the value of the critical exponent extracted from 4-point resistance measurements is lower than the true κ.

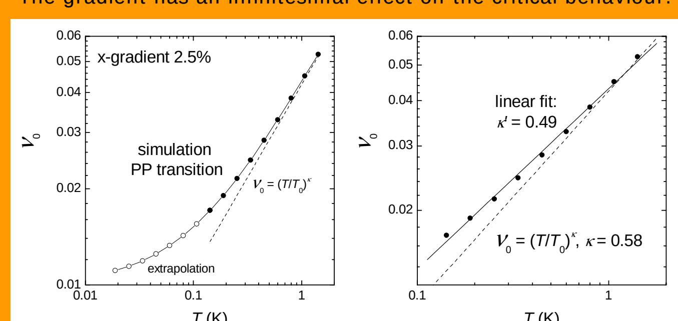
The PI transition represents an exceptional case, which can be solved analytically. The four-point resistances (in units h/e²) are:

$$R_{xy}(\nu)=1$$

$$R_{xx}(\nu)=\frac{L}{W}\rho_{xx}(\nu)N(\nu)$$

where the function $N(\nu)=\frac{\sinh(g_x)}{g_x}\frac{g_y}{\sinh(g_x)}\sim 1$ depends on the density gradients and temperature: $g_x=\frac{1}{2}\frac{\Delta n_x}{n}\frac{\nu}{\nu_0(T)}$, $g_y=\frac{1}{2}\frac{\Delta n_y}{n}\frac{\nu}{\nu_0(T)}$

The gradient has an infinitesimal effect on the critical behaviour.



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