Screening and transport in narrow quantum Hall systems

As a consequence of the singular Landau density of states, screening in an inhomogeneous two-dimensional electron system (2DES) subject to a strong perpendicular magnetic field B is, at low temperature T, extremely nonlinear. The system splits into "compressible" regions, in which screening is nearly perfect and the electron distribution arranges so that, within $k_B T$, a Landau level is pinned to the electrochemical potential $\mu^\star$, and into "incompressible" regions in between, in which $\mu^\star$ falls into a gap between adjacent Landau levels, so that there the Landau-level filling factor ν has a fixed integer value and, therefore, the electron density is constant [1-3]. Within an incompressible strip (IS) no elastic scattering is possible (since there are no states at the Fermi level), so that the longitudinal and the Hall resistivity there have the values of the free electron system with the same integer filling factor, i.e., in the limit $T \to 0$ results $\rho_\ell = 0$ and $\rho_H = h/(\nu e^2)$, respectively. In a narrow Hall bar, where the 2D electron density decreases monotonously from a maximum in the center to zero at the edges, ISs of finite width exist in certain intervals of the magnetic field B. If an imposed current leads to a stationary non-equilibrium state of the 2DES, according to the thermodynamic principle of minimum entropy production the current density concentrates on these ISs, where the current flows dissipationless. A quasi-local Ohmic transport theory, which in a homogeneous 2DES describes the Shubnikov-de Haas oscillations, combined with a self-consistent screening theory, describes the integer quantized Hall effect (IQHE) in narrow Hall bars, and the plateaus of the IQHE appear as the B-intervals in which sufficiently wide ISs exist [4-6]. Early [7] and more recent scanning force microscope measurements in the group of J. Weis confirm the predictions of this theory, and it is of great interest to investigate its further predictions, limitations, and possible extensions.

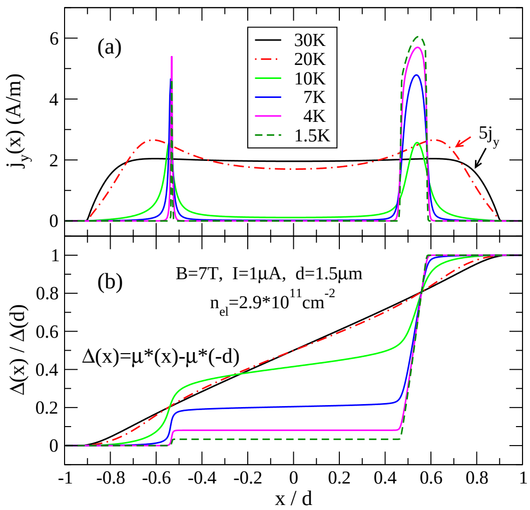

Figure 1: (a) Current density along and (b) normalized Hall potential across a Hall bar containing a 2DES with translation invariance in y-direction and lateral confinement in x-direction due to metallic gates in the half-planes $z = 0$, $x < -d$ and $z = 0$, $x > d = 1.5\,\mu$m. The imposed current $I = 1\,\mu$A and the magnetic field $B = 7\,$T are fixed. At higher temperature, $T \gtrsim 30\,$K, the current density is proportional to the electron density, and the Hall potential varies linearly across the 2DES. With decreasing T, the current density concentrates more and more around the stripes with local filling factor $\nu(x) = 2$, where incompressible stripes (ISs) form. In the limit $T \to 0$ all the imposed current flows dissipationless through, and the total Hall voltage drops across these ISs. Nonlinear feedback leads to strong asymmetries.

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