CURRENT CARRYING EDGE CHANNELS AND THE ROLE OF CONTACTS IN THE QUANTUM HALL REGIME

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By selectively populating spin resolved edge channels using Schottky gates we experimentally investigate the transition from adiabatic to equilibrated transport in the Quantum Hall regime. The scattering processes within a contact e. g. provide an excellent possibility to equilibrate nonequally populated edge channels. Here we demonstrate that not only with metallic reservoirs but also with increasing temperature one can study the crossover from adiabatic to equilibrated transport. Increasing the current results in a transition from edge channel to bulk transport.

Within the edge channel picture [1,2] the transport in the Quantum Hall regime is governed by current carrying edge channels. Classically these one-dimensional states correspond to skipping orbits moving along the sample boundaries. As long as the Hall voltage is much smaller than $\hbar\omega_c/e$ where $\hbar\omega_c$ is the cyclotron energy the Landau levels (LL's) in the bulk are supposed to be flat across the Hall bar. Under this condition the current should flow exclusively at the edges of the device. The number of edge channels corresponds to the filling factor in the bulk. Using negatively biased Schottky gates we can selectively populate these edge channels which now carry different amounts of current. The nonequilibrium distribution can be maintained over macroscopic distances ($\geq 200\mu m$ [3]) where the relevant length depends on the interchannel scattering rate. Here we investigate the influence of temperature and current level on such nonequilibrated transport.

In Fig.1 we show the structure of our devices. We use Schottky gates evaporated across the Hall bar. The injector gate (G1) selectively populates the edge channels, whereas the detector gate (G2) selectively detects them. Within this work the current is applied between contacts 1 and 2 and the Hall voltage is measured as a function of the detector gate voltage between the contacts 3 and 4 ($R_{12,34}$).

Our devices are modulation doped GaAs-AlGaAs heterostructures with carrier densities ranging between $1.8 \times 10^{11} cm^{-2}$ and $2.1 \times 10^{11} cm^{-2}$ and mobilities between $0.9 \times 10^{6} cm^{2}/Vs$ and $1.2 \times 10^{6} cm^{2}/Vs$ at liquid helium temperature. The measurements are carried out at temperatures down to $30 mK$.

In Fig.2 $R_{12,34}$ (solid line) displays a series of plateaus corresponding to an integer filling factor g_2 for edge channels running counterclockwise. Calculating $R_{12,34}$ within the Landauer-Büttiker formalism [1] one gets for the case of adiabatic transport

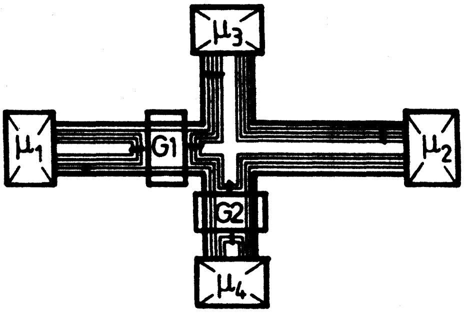

Figure 1: Schematic layout of the investigated samples with the two Schottky gates G1, G2 and the corresponding filling factors g_1, g_2 underneath. Transmitted and reflected edge channels for $b = 4$ (filling factor in the bulk), $g_1 = 1$ and $g_2 = 2$ are sketched.

$R^{ad}_{12,34} = h/e^2 g_2$ for $g_1 \leq g_2 \leq b$. Analysing the experimental data according to [4)]

$$R_{12,34} = (h/e^2 g_2) \sum_{i=1}^{g_2} (I_i/I)$$

with I_i the current carried by the i-th edge channel and I the total net current, one gets the distribution of the net current among the different edge channels.

At the injector gate 100% of the current is carried by the lowest edge channel. After travelling $45\mu m$ from the injector to the detector gate at the lowest temperature 65% of the total net current ($I = 10nA$) is still carried by the lowest edge channel, 28% is in the second edge channel, 5% in the third and 2% in the forth. The experiment demonstrates that the nonequilibrated distribution can be maintained over macroscopic distances and that not only a decoupled uppermost LL [4)] provides a mechanism for the nonequilibrated phenomena discovered recently [5,6)]. With increasing temperature the distribution is pushed towards the equilibrated distribution of equally populated edge channels as is displayed in the inset of Fig.2. The stronger coupling between the edge channels on the way from the injector to the detector gate is in qualitative agreement with the increase of the inelastic inter-edge channel scattering rate [7)] due to the increasing temperature. Note, however, that even for 1K only a small fraction of the current flows in the uppermost (spin split) edge channels. For equilibrated transport one expects $R^{eq}_{12,34} = h/e^2 b$. This value can also be obtained by reversing the direction of the magnetic field because now the selectively populated edge channels are running from the injector gate to contact 4 where they are equilibrated.

One can also push the distribution towards the equilibrated one by increasing the distance between the injector and the detector gate. Another possibility to switch between adiabatic and equilibrated transport is to connect electrically an additional

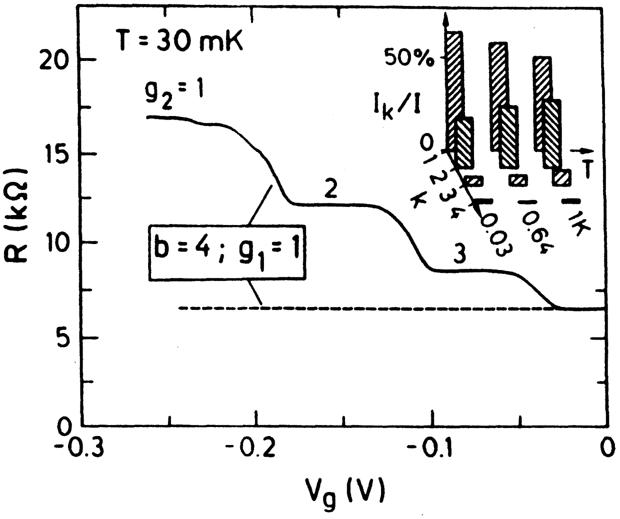

Figure 2: Hall resistance $R_{12,34}$ as a function of the detector gate voltage for filling factor $b = 4$ in the bulk and a filling factor of 1 under the injector gate. The inset shows the percentage of current in the i-th edge channel for four different temperatures.

ohmic contact to the 2DEG between the injector and the detector gate. We have demonstrated this type of switching in a recent experiment [3)].

In Fig.3 we have plotted the dependence of $R_{12,34}$ on the current level, carrying out the same experiment as above for different applied currents. At a current of $10nA$ three distinct plateaus are developed. With increasing current the plateaus are washed out and the measured resistance moves towards the equilibrated value. For a current of $10nA$ there is a clear selective population of the edge channels whereas at $1\mu A$ all edge channels seem to carry the same amount of current (inset Fig.3).

This is in contrast to Fig.2 where at 1K the uppermost LL is essentially decoupled. One possible explanation is that a higher current provides effective interchannel scattering. Ohmic heating of the lattice as equilibration process is unlikely since the heating at $1\mu A$ seems unsufficient to explain such a drastic effect. On the other hand it is realistic to assume that for higher currents the LL's in the bulk are no longer flat. As a consequence, the current flows not only in the edge channels but also in the bulk of the device [8)].

In summary we have discussed switching between adiabatic and equilibrated transport using either contacts, increased temperature or current. The results obtained by increasing the current may be interpreted as crossover from 1d- edge channel transport to 2d-bulk transport.

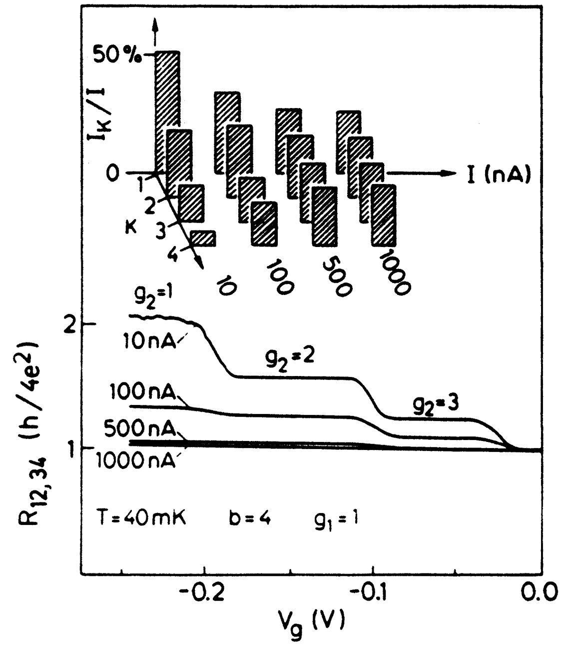

Figure 3: Hall resistance $R_{12,34}$ for four different currents. The inset shows the current distribution among the different edge channels. For $I = 0.5\mu A$ $U_H \approx \hbar\omega_c/e$

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