Equilibration of integer quantum Hall edge channels studied by scanning gate microscopy


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The concept of one-dimensional (1D) edge channels can be successfully applied to the description of transport phenomena in two-dimensional electron systems (2DES) in the quantum Hall (QH) regime [1]. QH resistance is not sensitive to inter-channel scattering, but there is renewed interest in interactions between copropagating edge channels [2] mostly in view of possible applications in quantum information technology [3]. Inter-channel transport was studied in the past by several authors (for a review, see [1]), but only in devices with fixed channel interaction length \(d\). Here we demonstrate for the first time the use of scanning gate microscopy (SGM) to realize devices in which \(d\) can be tuned continuously. We shall argue that this level of control is crucial to pinpoint the exact mechanism of edge-edge interaction.

Figure 1 schematically illustrates our experiment: inner (\(i\)) and outer (\(o\)) edge channels originate from two distinct voltage contacts at potential \(V_1\) and \(V_2\), respectively. They propagate together for a distance \(d\) and are then separated and guided to two current contacts \(I_A\) and \(I_B\), respectively. In what follows we set \(V_1 = V\) and \(V_2 = 0\). If we assume that there is no equilibration between the two (spin-degenerate) edge channels, then \(I_A = 2e^2/h V\) and \(I_B = 0\). On the other hand, if we assume that the two edge channels equilibrate their voltage imbalance completely, then \(I_A = I_B = e^2/h V\). In a model of spatially-uniform interaction one expects differential conductance to scale as \(G_B \propto \partial V / \partial I_B = G_0 (1 - e^{-2d/l})\) with \(G_0 = e^2/h\) and \(l\) the equilibration length [4]. Therefore, a measurement of \(I_A\) and \(I_B\) as a function of \(d\) and \(V\) makes it possible to analyze the equilibration behavior and verify if it is indeed consistent with an exponential decay. Moreover it yields the value of \(l\) as a function of \(V\).

Devices were realized starting from a high-mobility AlGaAs/GaAs heterostructure. A 6 \(\mu m\)-long 1D channel of two Schottky-gates with a constriction gap of 1 \(\mu m\) was patterned on the sample. Experiments were performed at 300 mK and bulk 2DES filling factor \(\nu = 4\) (two spin-degenerate edge channels). The selective backscattering of individual edge channels was achieved by the biased tip of a SGM, as described in detail in Ref. [5]. The inner and outer edge channels meet at the entrance of the 1D channel and travel in close proximity for a distance \(d\) before they are separated by the action of the SGM tip. Figure 2 shows the resulting differential conductance \(G_B\) as a function of \(d\) for a voltage \(V = 5\) mV. The curve starts for \(d = 0\) at \(G_B = 0\), i.e. no equilibration occurs, and nearly reaches \(G_B = e^2/h\) for \(d \sim 5\) \(\mu m\), i.e. complete equilibration is achieved.

We shall discuss our experimental results based on a theoretical model which takes into account the effect of impurities present in the 1D channel.

![Fig. 1: Sketch of the experimental setup](image1)

![Fig. 2: Conductance \(G_B\) vs. \(d\); from fit: \(l = 4.5\) \(\mu m\)](image2)


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