Luttinger liquids probed by artificial impurities in fractional quantum hall states

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A two dimensional electron gas (2DEG) immersed in a strong perpendicular magnetic field can display the characteristic manifestations of the fractional quantum Hall (FQH) effect. FQH liquids are remarkable emergent states driven by electron-electron interactions. The fundamental charged excitations of FQH liquids are predicted to display fractional charges and fractional statistics. In addition, the one-dimensional (1D) edge states flowing at the boundary of incompressible FQH phases are expected to be equivalent to chiral Luttinger liquids (cLL), and thus to display a non-Fermi behavior.

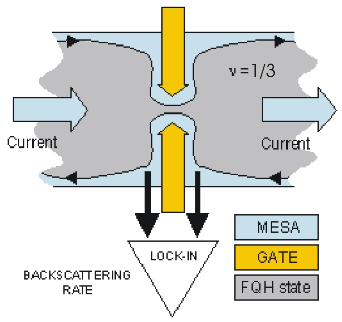


Fig. 1
Constrictions can be exploited to induce a controllable backscattering center between two counter-propagating edge channels. The inter-edge tunneling current is measured by means of a phase-locked technique.

Non-Fermi liquid behavior of edge states [1] can be probed by inducing a controllable inter-edge scattering at a nanofabricated quantum point contact (QPC) constriction. This system was previously used to measure line-shapes in resonant inter-edge tunneling [2] or to infer the charge of the quasi-particles [3] in shot noise measurements [4]. Together with experiments in anti-dot configurations and in cleaved-edge overgrowth systems[5] [6] [7] these findings have uncovered some of the most remarkable manifestations of edge state transport in the FQH regime.

Here we report the investigation of the unexplored non-linear inter-edge scattering at a QPC constriction in the FQH regime (see Fig.1). Our measurements represent a finite-bias spectroscopy of the inter-edge tunnelling and offer new insights on the out-of-equilibrium properties of highly-correlated one-dimensional edge states. The results reviewed here reveal a rich behavior of the backscattering current and have led to a new interpretation of inter-edge tunnelling at a QPC constriction that involves a charge-conjugation argument.

These results are stimulating significant theoretical efforts on FQH edge state dynamics [8].

We recall that standard cLL theory predicts that constrictions in the FHQ regime should display a peculiar zero bias anomaly corresponding to a low-energy suppression of the transmission (enhanced reflection) through the constriction (see Fig.2 panel a). Our experimental results have shown that contrary to this usual assumption, the transport through the

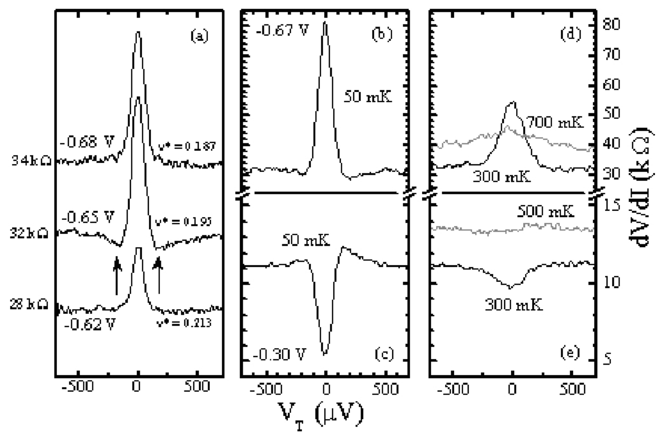


Fig. 2
Both transmission enhancement (panels a,b,c) and suppression (panels d,e) can be observed as a function of the split-gate parameters. These backscattering curves are obtained for an experimental condition compatible with a local constriction filling factor n*=1/5 and to its conjugate filling n*=2/7. The filling factor of the bulk is n=1/3.

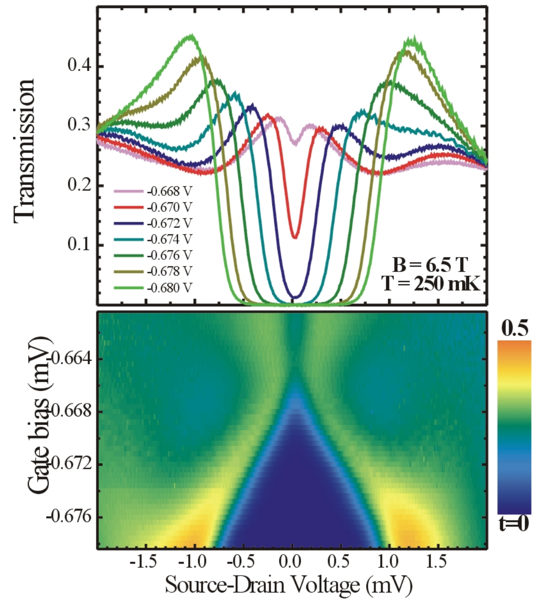


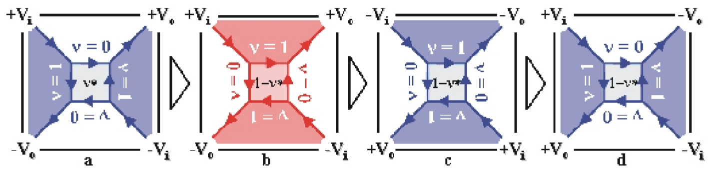
Fig. 3
Strongly non-linear backscattering can be observed in a constriction over a bulk filling factor n=1. These evidences demonstrate unambiguously that the local filling factor n* determines the behavior of the finite-bias backscattering at the constriction.

QPC constriction in the quantum Hall regime displays a more complex behavior and both low-energy suppression and enhancement of the transmission can be observed [9,10]. The different tunneling regimes can be realized in a controlled way by changing the voltage of the split-gate that is used to define the constriction. This evolution is linked to the effect of a local depletion of electrons within the constriction region leading to a local reduced filling factor n*.

The transmission suppression observed for n*<<n can be qualitatively *and* quantitatively understood in terms of backscattering in a Luttinger liquid [11]. To this end the experimental data were successfully compared with the results of a numerical analysis based on the approach developed by Fendley *et al.* [11]. The opposite regime of transmission enhancement, obtained for a weak constriction (n*»n), cannot be understood within available theoretical frameworks. Our recent experimental findings at n=1 [12] (see Fig.3) indicate that quantum Hall charge conjugation plays an important role in determining the behavior of the QPC as a function of the local filling factor inside the constriction. Our arguments imply that charge-conjugation could be in general a useful theoretical ingredient in determining the general behavior of edge channels. Figure 4 shows, thanks to a very simple argument, that a constriction has peculiar symmetry properties in relation to charge-conjugation and edge state tunneling. This simple model links for the first time this symmetry with the backscattering properties of a cLL.

An important part of this work was devoted to the fabrication of high-quality constrictions on low-density (less than 1´ 10^{11} cm^{-2}) and high-mobility (beyond 1´ 10^{6} cm^{2}/Vs) GaAs/AlGaAs heterostructures. During this work we explored

Fig. 4
A constriction over a bulk n=1 liquid remains a constriction once described in terms of holes. Due to particle hole symmetry, this leads to a peculiar overall structure in the tunneling characteristics. This structure is consistent with experimental evidences.



different fabrication techniques and geometries for QPCs and final devices were processed adopting a split-gating technique, which appeared to be the most suitable for our experiments. Sharp and regular quantization steps were observed at low-temperature (300 mK and below).

This research activity will continue by building on the acquired know-how and developing more complex mesoscopic circuits working in the FQH regime. In particular we plan to process constrictions connecting two-dimensional regions at different filling factors [13] (1 and 1/3 in the most simple case) as well as an inter-edge Fabry-Perot interferometer [14]. The first device addresses the problem of the injection of electrons into a FQH edges through an Andreev-like scattering. The second device can be used to study the fractional statistics of the quasi-particles in the FQH regime.

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