Intralayer Correlation and Charge Imbalance Effects on the Stability of the Bilayer Coherent ν = 1 Quantum Hall State

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When Tsui, Störmer and Gossard first took 2D electron systems (2DESs) to the extremes of magnetic field and sample purity, they saw that the intralayer Coulomb interaction between the electrons resulted in entirely new quantum fluids of fractionally charged quasi-particles [1]. When two of these 2DESs are brought into close proximity, interlayer Coulomb interactions also drive the bilayer system into new phases of matter that have no single layer analogue [2, 3]. The strength of the interlayer Coulomb interactions is set by the distance d between the layers while the strength of the intralayer interactions is determined by the magnetic length $l_B \propto 1/\sqrt{B}$. The ratio of these two parameters d/l_B indicates the relative strengths of the interactions and this governs the macroscopic properties of the system. For d/l_B below 1.8, the interlayer interactions become sufficiently strong when compared to the intralayer interactions that the bilayer spontaneously develops a macroscopic order [2-5]. In this state, the electrons in both layers form a phase coherent, many-body wavefunction that extends across the entire system [6]. Fortunately, this quantum phase transition from a single particle to many-body wavefunction can be controlled by adjusting d/l_B. This can be done easily in bilayers by tuning the total carrier density. This makes bilayers ideal for studying the interplay between intra- and inter- layer interactions in macroscopically coherent systems.

We report on two key effects. Firstly we examine five bilayer systems that range from being strongly coherent to incoherent by adjusting the total carrier density in the bilayer. In particular, we focus on the stability of the $\nu_{\text{total}} = 1$ bilayer quantum Hall state. This state can exist even if neither layer exhibits a quantum Hall state, but only under the condition that there is interlayer coherence or a symmetric-antisymmetric gap due to tunneling [7]. An advantage of bilayer hole samples is that very narrow insulating barriers suppress tunneling (see Figure 2) so that the $\nu_{\text{total}} = 1$ state is stabilized only by interlayer coherence.

Secondly, we study the coherent $\nu_{total} = 1$ state at different levels of imbalance. Here, the word imbalance refers to taking the charge balanced case $\nu_{\text{total}} = ½ + ½$ and moving charge from one layer to another while maintaining a constant total density. It was theoretically predicted that $\nu_{\text{total}} = 1$ quantum Hall state should become more stable as system is imbalanced [8]. Recently, Tutuc *et al.* [9] verified this experimentally for small deviations away from the balanced point and for a single $d/l_B = 1.45$. However, so far the theory and experiment have neglected strong intralayer correlations. We have performed imbalance experiments that take the system from $\nu_{\text{total}} = ½ + ½$ all the way through to the single layer transition where $\nu_{\text{total}} = 1 + 0$. We have done this for d/l_B equal to 1.26, 1.36, 1.53, 1.68 and 1.80, which cover the regimes of strongly coherent, weakly coherent and incoherent bilayers. In each case we have mapped the strength of the $\nu_{\text{total}} = 1$ minima as they evolve during the imbalance. *We find that for strongly coherent systems, the theory describes the data well but for weakly coherent bilayers, the intralayer interactions must be incorporated into the theory. As foreseen in Ref. [8], we see the most significant deviations from the theory are most obvious at $\nu_{total} = 1/3 + 2/3$, when the intralayer correlation is at its greatest. Deviations may be due to competition from incoherent single layer states and our results strongly indicate the need for more theoretical studies of the excitations of imbalanced bilayer.*

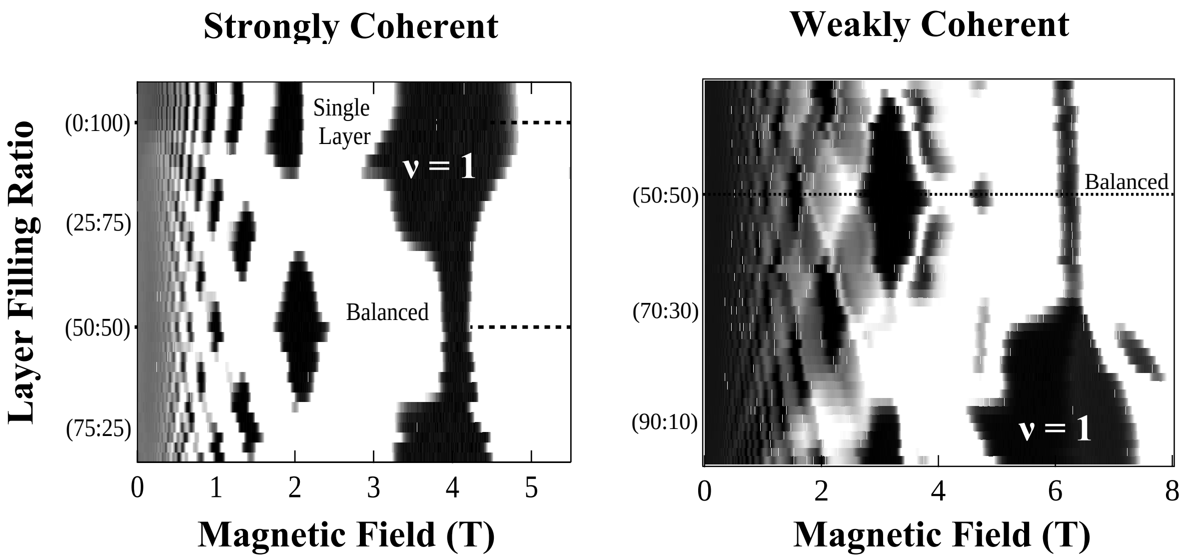
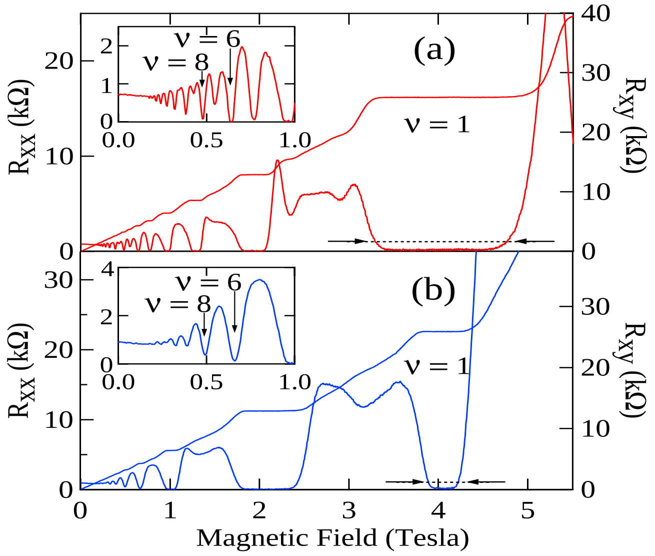


Figure 1: Two greyscales from imbalance experiments performed in the strongly coherent and weakly coherent regimes. Each row in the greyscales is constructed from ρ_{xx} data that was obtained when the magnetic field was swept at each stage of the charge imbalance. The continuous and vertical, dark region on the right of each greyscale corresponds to the $\nu_{total} = 1$ ρ_{xx} minimum as the system is shifted away from the balanced case and towards a system in which all the charge is in a single layer. The width of this dark region is an indication of the stability of the $\nu_{total} = 1$ state.

Figure 2: Shubnikov-de Haas and Hall traces obtained at $d/l_B = 1.36$ for (a) the system with all charge in only one layer and (b) the balanced state bilayer system where the total carrier density is spread evenly across the two layers. Both insets show low field SdH oscillations. The absence of minima at odd filling factors in the bilayer system (inset (b)) verifies negligible tunneling between layers. Lattice temperature is 55mK



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