0.7 Structure in Quantum Wires Observed at Crossings of Spin-Polarised Subbands

A C Graham[1], **K J Thomas**[1], **M Pepper**[1], **M Y Simmons**[2], **D A Ritchie**[1]

(1)Cavendish Laboratory, Madingley Road, Cambridge, CB3 OHE, United Kingdom
(2)University of New South Wales, School of Physics, Sydney, NSW 2052, Australia

We report spontaneous splitting at the crossing points of two spin-polarised one-dimensional (1D) subbands of opposite spin in ballistic quantum wires, defined in GaAs/AlGaAs heterostructures. In an in-plane magnetic field, $B_{||}$, conductance plateaux are observed at intervals of e^2/h due to Zeeman-splitting of the 1D subbands. As $B_{||}$ increases, the spin-up level of the N^{th} mode and the spin down level of the $N+1^{th}$ mode cross, where N is the index of the degenerate 1D subband. We observe a spontaneous splitting at the level crossings for $N < 3$, giving rise to a feature similar to the 0.7 structure [1]. This '0.7 analogue' observed just below the $3e^2/h$ plateau evolves to the $2e^2/h$ plateau as $B_{||}$ increases further. At the crossings of the higher modes, this effect is weakly present, and it has also been observed at second crossings. It is shown that the magnetic field and temperature dependence of this '0.7 analogue' is similar to that of the 0.7 structure. This phenomenon has been observed in the conductance of four different samples and is reproducible on subsequent cool-downs. The feature is also unaffected when different biases are applied to each split-gate and the quantum wire is shifted laterally in the plane of the 2DEG.

At a crossing, levels are degenerate, therefore transport at the Fermi energy through two channels becomes possible. The spin-split conductance plateaux present at all integer values of e^2/h in a magnetic field evolve to plateaux at *only odd-integer* values of e^2/h as the crossing occurs. Figure 1(a) shows differential conductance $G = \frac{dI}{dV}$, measured as a function of split-gate voltage V_{g} at fixed in-plane magnetic fields $B_{||}$. At $B_{||} = 0$ (left trace), usual quantised conductance plateaux are present at $2Ne^2/h$. As $B_{||}$ increases to 16 T (right trace), three major changes occur. Firstly, each spin-degenerate 1D subband splits into two and new conductance plateaus appear at $(N+\frac{1}{2})2e^2/h$. Secondly, with further increase of $B_{||}$, the half-integer plateaux strengthen and integer plateaux weaken. The split levels with opposite spins from the N and $N+1$ modes cross when the Zeeman energy $2g\mu_B BS$ is equal to the subband energy spacing at $B_{||} = 0$, where g is the g-factor, μ_B is the Bohr magneton and $S = \frac{1}{2}$ is the electron spin. Thirdly, with further increase of $B_{||}$, half-integer plateaux weaken and integer plateaux reappear at the second crossing of energy levels. However, as the lowest subband cannot cross with any other, the plateau at e^2/h remains.

In agreement with previous results, the 0.7 structure drops to $0.5(2e^2/h)$ with increasing $B_{||}$. In addition, figure 1(b) shows a shoulder-like feature appearing just below the plateau at $3e^2/h$ when the up and down spin subbands of the $N = 1$ and $N = 2$ modes intersect as $B_{||}$ is increased. It is observed that this feature strengthens and drops to $2e^2/h$ with increasing $B_{||}$. This strongly resembles the evolution of the 0.7 structure to $0.5(2e^2/h)$ as $B_{||}$ increases. The temperature dependence of this '0.7 analogue' is also comparable to the 0.7 structure [2]. Figure 2 shows a 3D grey-scale plot of the transconductance as a function of V_g and $B_{||}$. The white regions represent plateaux and the black lines are the risers between them. The '0.7 analogue' appears as a spontaneous splitting between the second and third risers from the left as indicated by the $*$ symbol. It is evident that this feature also occurs at the crossings of higher subbands and at second crossings, as indicated by a $\star$ and a $+$ respectively. On close examination, this discontinuity looks similar to the splitting at $B_{||} = 0$ caused by the 0.7 structure, marked by a $\times$ symbol.

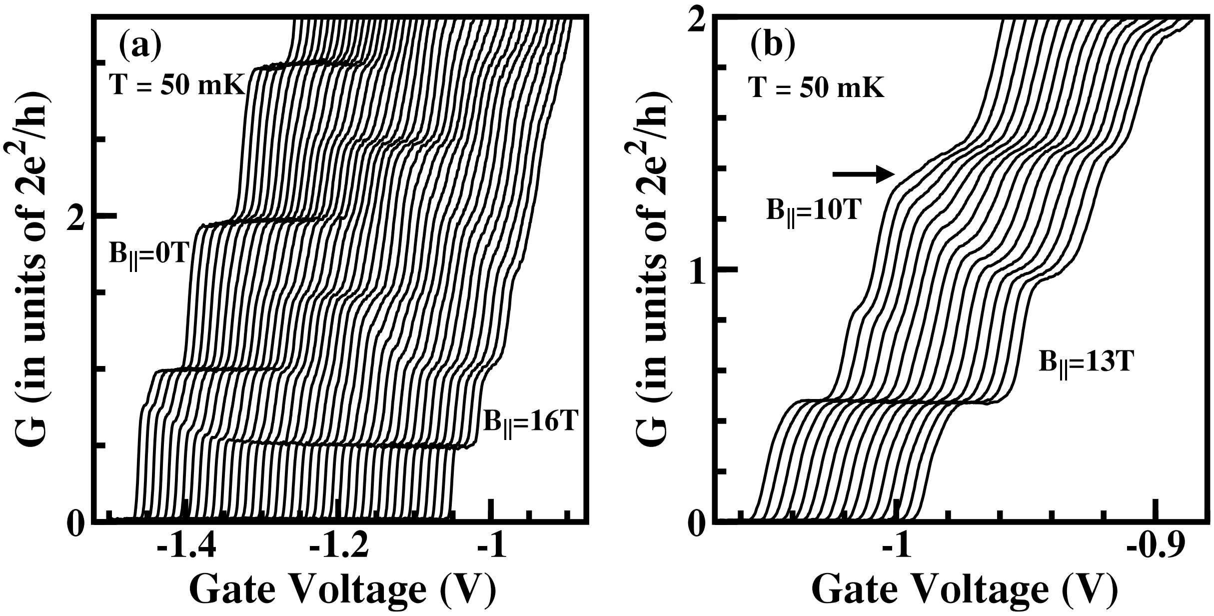

Figure 1: (a) Conductance $G(V_g)$ characteristics at different parallel magnetic fields from 0T to 16T. (b) A close-up of the region of the first crossing of N=1$\uparrow$ with N=2$\downarrow$. The shoulder-like feature (marked by a horizontal arrow) on the edge of the $3e^2/h$ plateau at 10T drops to $2e^2/h$ as magnetic field increases. The traces in (a) and (b) are offset horizontally for clarity.

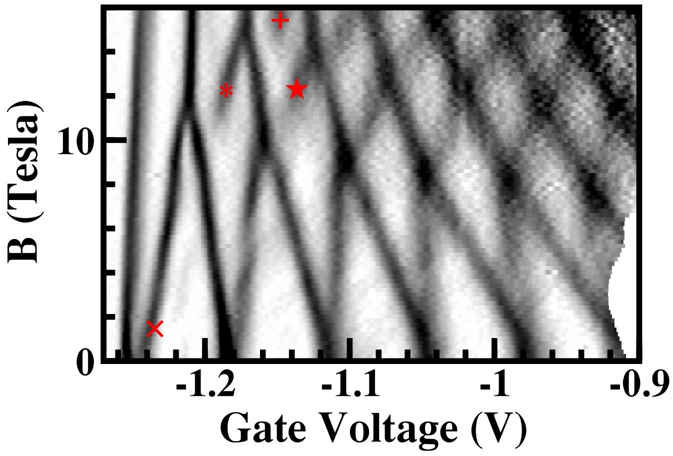

Figure 2: Transconductance as a function of gate voltage and magnetic field - the white regions correspond to plateaux and the black line are the risers between them. The symbols are explained in the text.

References

[1] K. J. Thomas, J. T. Nicholls, M. Y. Simmons, M. Pepper, D. R. Mace, and D. A. Ritchie, Phys. Rev. Lett. **77**, 135 (1996).

[2] K. J. Thomas, J. T. Nicholls, M. Pepper, M. Y. Simmons, D. R. Mace, and D. A. Ritchie, Physica E **12**, 708 (2002).