Quantum Hall Ferromagnetism of AlAs 2D electrons

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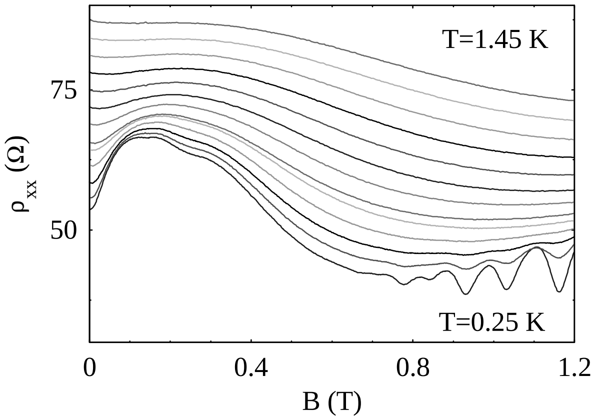
Recently there has been renewed interest in the physics occuring when two Landau levels with opposite spin in a semiconductor become degenerate, a subject known as quantum Hall ferromagnetism. Here we report the realisation of such Landau level (LL) crossings in record mobility (>300.000 cm^2/Vs) AlAs 2DEGs.

Temperature and tilt angle-dependent magneto-resistance measurements were carried out on Hall bars. Our main results are summarised as follows: i) In low magnetic fields a large positive magneto-resistance is observed and attributed to scattering of electrons between the two occupied valleys. ii) Integer and higher order Fractional quantum Hall effects are observed iii) From the position of the coincidences of LLs in tilted fields, we obtain for low filling factor (high *B*) a highly non-linear magnetic field dependent exchange energy contrary to[1]. iv) At low *T* and high *B*, a huge hysteresis at, and a shifting of the LL coincidences is observed, i.e. the exchange enhancement is found to be temperature and history dependent. v) For high filling factor and low *B* (when the product of m*g* is not magnetic field dependent) the valley splitting is a linear function of the perpendicular magnetic field (c.f.[2]).

In our quantum wells the electrons occupy both in-plane X-valleys as evidenced by beatings in the low field magneto-resistance (inset fig2). At low *B* and *T*, a large positive magneto resistance is observed (fig1) which is attributed to scattering of the electrons from one in-plane valley to the other. At higher *B*, both the integer and (higher order) fractional quantum Hall effects are fully developped (fig2)

Because of the relatively small cyclotron energy ($m^* = 0.48\ m_0$) and the rather large *g*-factor (g_0=+1.96 ; g^* up to 5xg_0) of AlAs X-valley electrons, crossing of LLs with different spin can be obtained at relatively moderate tilt angles of the sample in the magnetic field. The Landau level crossings evidence themselves by a nearly vanishing energy gap and the appearance of a spike in the resistance (fig3). From the position of the LL crossings in the sin(tiltangle) vs B_{perp}-plane (fig4), the difference in exchange energies of the various LL is determined. Unlike ref[1], for low fillingfactors (high *B*) this difference is a non-linear function of *B*. Moreover, the LL coincidences at high *B* are observed to be strongly *B*-history dependent. Their *T*-dependence (inset fig3) implies a temperature dependent exchange enhancement presumably due to electron-electron interactions. Contrary to case of GaAs electrons[3], the X-valley AlAs electrons couple only very weakly to the nuclear spin system as they consist mostly of p-wave. Thermal nuclear spin polarisation can thus not be the cause. The LL coincidences at low *B* and higher tilt angle (fig4) allow determination of the valley splitting (c.f.[2]), which is found to be linearly increasing with the perpendicular magnetic field.

[1] E.P. de Poortere et al., Science **290**, 1546 (2000)
[2] Y.P.Shkolnikov et al., Phys. Rev. Lett. **89**, 226805 (2002)
[3] S. Kraus et al., Phys. Rev. Lett. **89**, 266801 (2002)



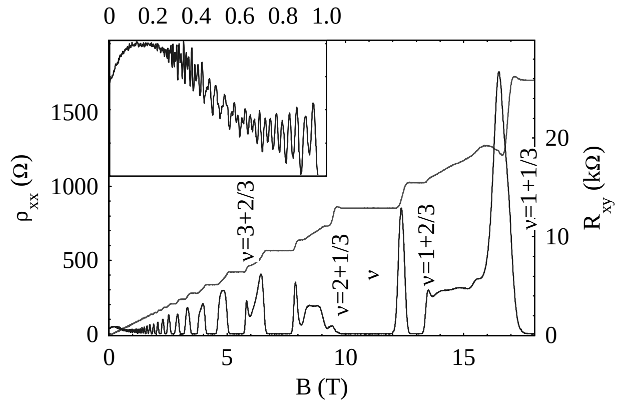
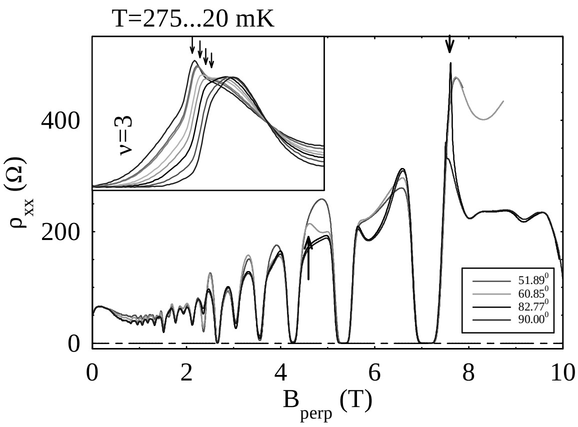


Fig1. Temperature dependence of the low field positive magneto-resistance that disappears around 1K.

Fig2. Integer and higher order fractional quantum Hall effects at T=20mK. Inset plots the low field SdH-oscillations. A clear beating originating from Landau levels from the 2 occupied valleys is seen.



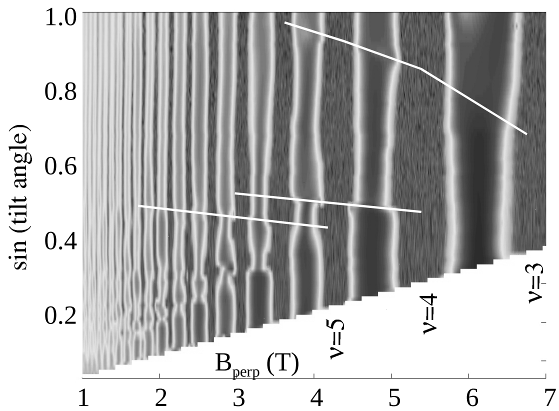


Fig3. ρ_{xx} vs B_{perp} for various tilt angles T=0.25 K. Arrows indicate LL crossings. Inset: temperature dependence of ρ_{xx} at the LL crossing, showing a shift to higher B_{perp} for lower T.

Fig4. Color plot of ρ_{xx} vs B_{perp} and the sine of the tilt angle T=20 mK. Landau level crossings are easily identified. From the low B-field pattern, the valley splitting is deduced.