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THE TEMPERATURE DEPENDENCE OF THE THREE-DIMENSIONAL ANALOGUE OF THE QUANTUM HALL EFFECT IN SEMIMAGNETIC $Hg_{1-x}Fe_xSe$

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Due to the pinning of the Fermi energy to a localised donor state in $Hg_{1-x}Fe_xSe$ the free carrier concentration oscillates in an applied external magnetic field. We measured the resulting modulations of the Hall resistance in fields up to 17.5 T and at temperatures between 4.2 K and 30 K.

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$Hg_{1-x}Fe_xSe$ with Fe concentrations above $5 \times 10^{18}\text{cm}^{-3}$ is a mixed valence system with a Fermi energy pinned to the localised donor state [1]. Oscillations of the density of states caused by an applied external magnetic field, thus lead to a bidirectional charge transfer between the impurities and the quasi-free electron gas. These fluctuations of the free carrier concentration could be observed as modulations of the Hall voltage [2] with an amplitude of about 0.8 % at $T =$ 4.2 K.

We measured the temperature dependence of this effect in fields up to 17.5 T and at temperatures up to 30 K in an unoriented sample with an iron concentration of $5 \times 10^{19}\text{cm}^{-3}$ and compared it with simultaneously recorded Shubnikov-de Haas oscillations. We found no phase shifting between Hall and Shubnikov-de Haas oscillations, thus scattering effects as a cause for the Hall voltage modulations described by Mani et al. [3] can be excluded.

We observed an independence of the average free carrier concentration from temperature in the considered range. Mobility measurements up to 30 K showed only a decrease of about 10 % so that a temperature independent Landau-level halfwidth can be used to calculate the concentration of the quasi-free carriers $\int f(E)\, D(E) \mathrm{d}E$ (Fig. 1). The thermal broadening of the Hall oscillations is therefore essentially caused by the smoothing of the Fermi distribution $f(E)$.

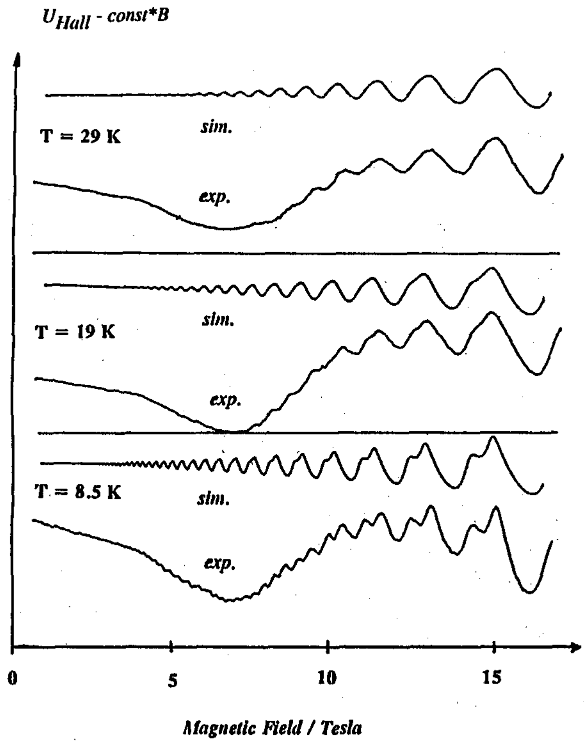

Fig. 1. Modulations of the Hall resistance (the linear part of the Hall voltage was subtracted) of $Hg_{1-x}Fe_xSe$ with $5 \times 10^{18}cm^{-3}$ iron content for three different temperatures compared with numerical simulations. The bumping of the experimental curves between 5 and 10 T is caused by nonlinearities of the Bitter coil.

Measurements of a sample with an iron concentration of $3 \times 10^{18}cm^{-3}$ showed also oscillations in the Hall resistance. The exact correspondence of the positions of the Shubnikov-de Haas oscillations with those of higher doped samples proves that the Fermi level has been already degenerated with the localised state for that Fe concentration. We assume that the missing 2×10^{18} carriers per cm^3 are provided by defects of the HgSe host lattice. The fact that we measured a carrier concentration of about $3 \times 10^{18}cm^{-3}$ in samples with an iron concentration of $1 \times 10^{18}cm^{-3}$ confirms this concept.

Measurements with a $Hg_{0.88}Fe_{0.12}Se$ sample showed a strong modulation of the Hall voltage with an amplitude of 6 % at liquid helium temperature and a phase shifting of π with respect to the oscillations of the transverse magnetoresistance (Fig. 2). We have no explanation yet for this striking behavior, but we can exclude sample inhomogenities because of a high symmetry of the experimental results in both directions of the magnetic field. The measurements on a sample containing

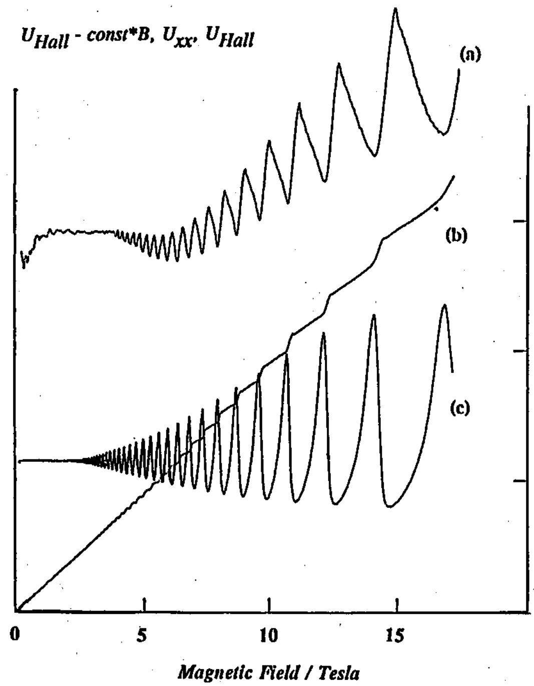

Fig. 2. Magnetotransport in $Hg_{0.88}Fe_{0.12}Se$; (a) shows the strong modulation of the Hall resistance (the linear part of the Hall voltage was subtracted) with saw-tooth like oscillations shifted by π with respect to the transverse magnetoresistance oscillations (c); curve (b) shows the original recorded Hall voltage; the step-like modulation is already clearly observable without subtraction of the linear part.

10 % iron showed similar results.

We tried to fit Kossut–Gałązka-model [4] to our experimental Shubnikov-de Haas data of a sample with an iron concentration of 5×10^{19} cm^{-3}. Neglecting far band contributions ($\gamma_i = \kappa = F = 0$ with $i = 1, 2, 3$) we adopted the HgSe parameters $E_g = -272$ meV for the band gap and $\Delta = 383$ meV for the spin–orbit splitting [5, 6]. Then the best fit was obtained with an interband momentum matrix element $P = 6.63 \times 10^{-8}$ eVcm and total exchange interaction parameters $x \times \alpha = -3$ meV and $x \times \beta = +5$ meV. If one considers only the Fe^{3+} ions as magnetically active ($x = 0.0002$), one would get unrealistically high values for α and β of about 15 eV. This seems to indicate that the Fe^{2+} impurities contribute also to the exchange interaction in an unnegligible way.

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