Effect of Screening on Spin Polarization in a Two-Dimensional Electron Gas

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Among spin related phenomena one of the most intriguing is a spontaneous spin polarization (magnetization) of a two-dimensional electron gas (2DEG). In absence of direct methods to measure a 2DEG magnetization only indirect evidence is so far available. The experiments of A.A.Shashkin et al. [1] revealed almost a linear dependence of a critical magnetic field B_c of full spin polarization versus 2DEG density n. The full polarization state was associated with the onset of a saturation of a magnetoresistance in a parallel magnetic field. The extrapolation of the experimental curve to $B_c = 0$ gave a non-zero value of n. It looked as a manifestation of a possibility of spontaneous spin polarization for lower electron density. However, in the recent experiments of Pudalov et al. [2] a break-through to a more dilute 2DEG discovered a substantial declination of $B_c(n)$ curve from that extrapolated in [1]. A possibility of spontaneous spin polarization remained thus still unclear [3,4].

The main goal of present communication is to elucidate the impact of screening on a 2DEG spin polarization. Just screening results in the dependence $B_c(n)$ similar to that in the experiment.

We adopted a simple model for Coulomb potential $V(q)$ accounting for a screening length λ: 1) $V(q) \sim 2\pi e^2\lambda/\kappa$ for $q < 1/\lambda$; 2) $V(q) \sim 2\pi e^2/\kappa q$ (that is unscreened potential) for $q > 1/\lambda$.

The polarization degree $\eta = |n_+ - n_-|/n$ where n_+ and n_- were respectively spin-up and spin-down electron densities was derived via minimization of a total energy E_{tot} including kinetic, interaction (exchange), and Zeeman contributions. We exploited a quite common model

$$E_{tot} = \{\frac{\pi\hbar^2}{4m}(n_+^2 + n_-^2)\} - \{I(n_+) + I(n_-)\} - \{\frac{1}{2}g_0\mu_B B(n_+ - n_-)\} \qquad (1)$$

The interaction term $I(n_\pm) \sim (e^2/\kappa k_{F\pm})n_\pm^2$ (i.e. as that for unscreened potential) in the limit $k_{F\pm} >> 1/\lambda$ for the Fermi wave vector $k_{F\pm} = \sqrt{\pi n_\pm}$. In the opposite limit when $k_{F\pm} >> 1/\lambda$ the interaction term $I(n_\pm) \sim (e^2\lambda/\kappa)n_\pm^2$. In the intermediate range of $k_{F\pm}$ the interaction term $I(n_\pm)$ was numerically calculated for above mentioned screened Coulomb potential. Evidently, the critical field $B = B_c$ was associated with $\eta = 1$.

The calculated dependence $B_c(n)$ for $\lambda = 100nm$ is presented in Fig.1 (solid curve). It is close to that obtained experimentally in Ref.[4]. However, the achieved electron densities were above 0.7 $10^{11}cm^{-2}$. The calculated curve predicted spontaneous spin polarization for $n = 0.4\ 10^{11}cm^{-2}$ if the model screening length λ fitted to experimental curve in Ref.[4] is as large as 100nm. However, for fairly small screening length λ (for instance, if it approaches the Bohr radius) the screening results in both B_c and n simultaneously coming to zero and spontaneous spin polarization does not exists. It should be emphasized that for unscreened Coulomb potential the present model inevitably leads to existence of spontaneous spin polarization.

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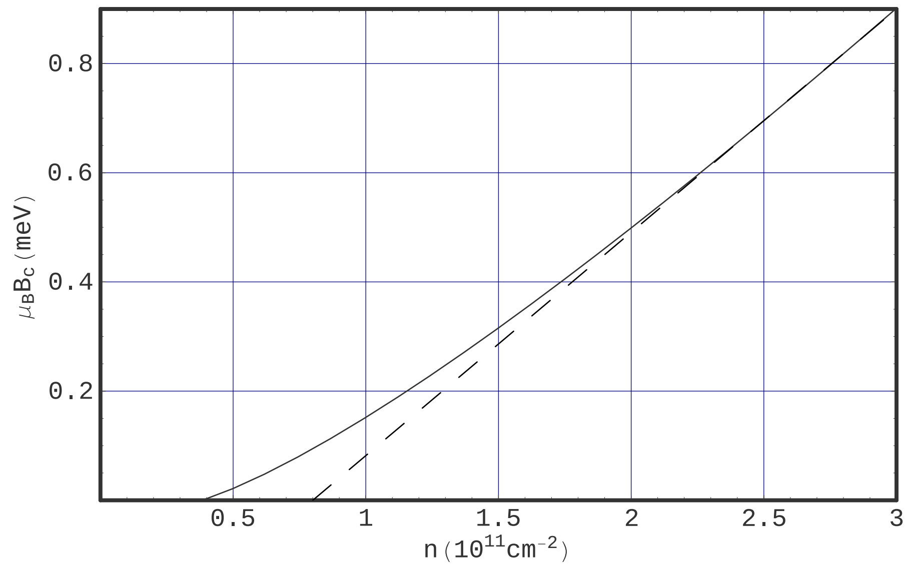

Figure 1: The calculated dependence $\mu_B B_c$ vs electron density n (solid line). The dashed line corresponds to the extrapolation as that in Ref. [1].

As for the partial spontaneous spin polarization ($\eta < 1$, $B = 0$) in the frame of the present model it is not possible. Unlike to induced spin polarization the spontaneous one has only an abrupt transition to fully polarized state for sufficiently low electron density.

Although no relation between conductivity and spin polarization were incorporated in the present model a plausible reason of the resistance growth and saturation seen in the experiments might be a lowered density of states at the Fermi level caused by spin polarization. This lowering exists in 1DEG [5] as well as in 2DEG [6].

References

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