Magnetoplasmons of the Two-Dimensional Electron System in a Parabolic Channel over Liquid Helium

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A lot of experimental and theoretical work have been performed in order to understand the collective modes of two-dimensional electron system (2DES) confined to restricted geometries. In particular, the system of surface electrons on helium has provided a very convenient tool to study edge magnetoplasmon properties at the nondegenerate regime. Recently, magnetoplasma excitations in a single wire of electrons on suspended helium films were reported.[1]

In this work we study the magnetoplasma waves in the nondegenerate 2DES laterally confined in a narrow channel of width W by a self-consistent potential given, in the parabolic approximation, by $V_y = m^*\Omega^2 y^2/2$, where Ω is the confinement frequency. First, we have showed that this is a very good approximation for the experimental conditions of Ref. [1]. We have considered, for the actual situation, a metallic gate away from the 2D layer at distance d.

We calculate the magnetoplasmon modes for strong magnetic fields, $\omega_c/\Omega >> 1$ and in the ultra quantum limit when only the lowest (spin-split) Landau level is occupied, in particular, $\hbar\omega_c >> k_B T$. For evaluation of the spectra and the spatial structure of the magnetoplasmons, we employ an approach, based on the random-phase approximation, developed in Ref. [2]. The extension for this problem is not trivial because a new length scale $\ell_T = \sqrt{2k_B T/m^*\Omega^2} >> \ell_0$ is introduced, where ℓ_0 is the magnetic length. In Fig. 1, we show the exact dispersion relation for the first three magnetoplasmon modes obtained from the determinantal equation for the charge densities. The first (fundamental), the second, and the third modes are indicated by solid lines counting from the top, where $\omega^* = 2\sqrt{\pi}e^2\ell_0^2 n_s/\hbar\epsilon\ell_T$, with n_s is the electron density at the channel center and ϵ is the effective dielectric constant. The dotted and dot-dashed curves are the dispersions for the gated structure with $d = 10^{-2}$ cm and 10^{-3} cm. In the inset of Fig. 1, we show the phase velocity as a function of $(q_x\ell_T)^{-1}$. We observe that, for $d = 10^{-2}$ cm only the first mode is affected by the gate. However, for $d = 10^{-3}$ cm, the frequencies of all the three modes become essentially smaller due to effect of the gate.

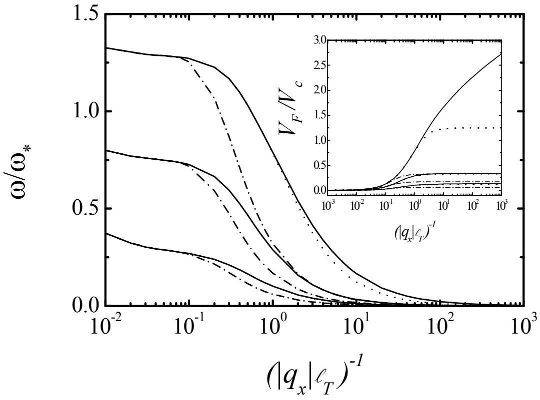

Fig. 1

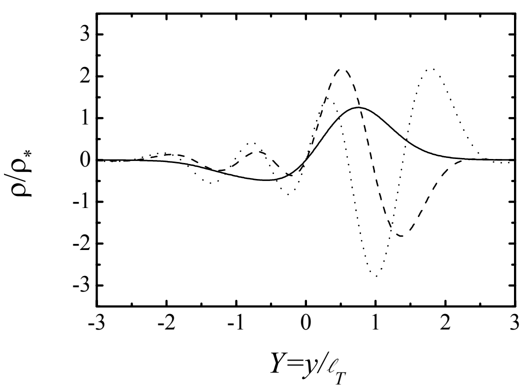

Fig. 2

For the fundamental mode, we found that the phase velocity $V_F = \omega/q_x$, for $d/\ell_T << 1$ and $q_x\ell_T << 1$, is given by

$$V_F = \frac{m^*\Omega^2\ell_0^2\ell_T}{\sqrt{2}\hbar} + \frac{e^2 f_0}{\hbar\epsilon}\frac{d}{\ell_T},$$

where f_0 is the Boltzmann factor. We observe that $V_F \propto d/\ell_T$, as found in Ref. [3], only if $d \gg d_a$, where $d_a = \sqrt{2}k_B T\epsilon\ell_0^2/e^2 f_0$.

In Fig. 2 we plot the charge density for the three first modes in the channel without the metallic gate for the conditions of Fig. 1.

We have also included the effect of dissipation on the magnetoplasmon spectra using the integral equation for the charge density given in Ref. [4]. In Fig. 3 we show Re $\omega/|\mathrm{Im}\ \omega|$ as a function of $(q_x\ell_T)^{-1}$, calculated from a 16×16 system of equations, for the first three modes corresponding to solid, dashed and the dotted curves. Here it is used $\Omega = 10^8$ s^{-1}, $n_s = 10^8$ cm^{-2}, $\epsilon = 3$, $T = 0.6$ K and $B = 3.4$ T, taken from Ref. [1]. The top (bottom) solid, dashed, dotted and dash-dotted curve correspond to $\tau^* = 10^{-8}$ s ($\tau^* = 10^{-9}$ s), where τ^* is the relaxation time that appears in the Drude-like formula. In Fig. 4 we depict Re ω/ω_{AC} as a function of $(q_x\ell_T)^{-1}$, where $\omega_{AC}/2\pi = 10$ kHz is the excitation frequency of Ref. [1].

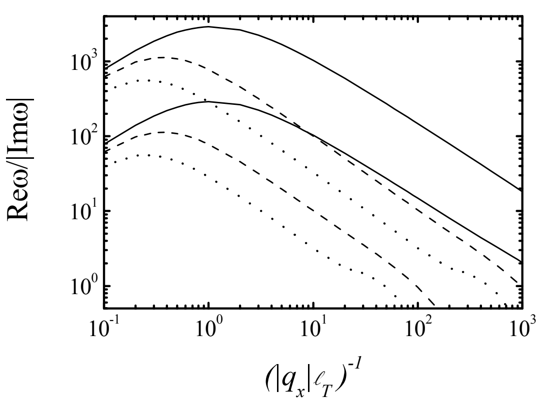

Fig. 3

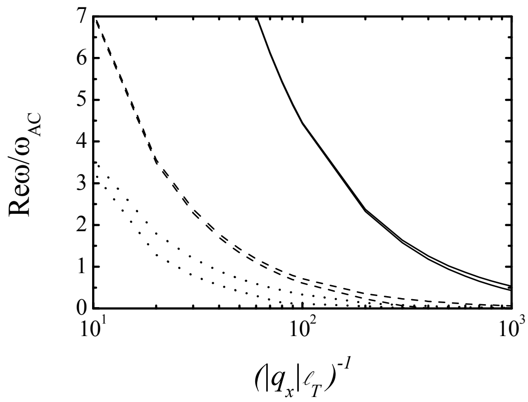

Fig. 4

From a detailed comparison between of our numerical calculations and the experimental results from Ref. [1], we concluded that: i) for the fixed $q_x^{(n)} = (2\pi/P)n$, where P is the channel perimeter, the frequency of any magnetoplasmon is $\propto 1/B$ in agreement with experiment and the earlier theoretical calculation;[5] ii) the fundamental mode was not observed in the experiment, but the upper order modes; iii) despite the self-consistent calculation of the charge profile, our model is unable to explain the dependence of the mode spectra on the holding potential as found in Ref. [1].

References

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