Edgemagnetoplasmons in a partially screened system

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Abstract

We present a study of partially screened edgemagnetoplasmon modes to test theoretical predictions. Fetter's theory fits the data for small magnetic fields. Deviations at larger fields occur when the penetration length becomes shorter than the width of the density profile at the sample perimeter. At large fields the resonant mode frequencies are in reasonable agreement with the theoretical predictions of Volkov and Mikhailov.

Key words: edgemagnetoplasmons; two-dimensional electrons;

Edgemagnetoplasmons (EMP) were discovered independently for electrons on a helium surface by Mast et al.[1] for the partially screened case and for the fully screened case by Glattli et al.[2] Further studies have been made of partially screened EMP in the high magnetic field limit for the overdamped case [3] and for resonant modes[4]. We present data for partial screening at small and intermediate magnetic fields in order to test theories in these limits.

Both Fetter[5] and Volkov and Mikhailov[6] solved for the EMP modes in a disk geometry of radius R with a sharp density profile at the perimeter and electrons screened by metal plates located a distance h above and below the sample. Fetter reduced the problem to an equivalent matrix problem. The mode frequencies of azimuthal number L, $\omega(q = L/R)$ with R as the sample radius, are given by a solution to

$$\sum_{j=0}^{\infty}[K_{ij}\Omega_0^2 - (\omega-\omega_c)^2\gamma_{ij} - (\omega^2-\omega_c)^2 g_{ij}]c_j = 0. \quad (1)$$

where ω_c is the cyclotron frequency, and

$$\Omega_0^2 = \frac{ne^2\tanh(h/R)}{mR\epsilon_0(\epsilon+1).} \quad (2)$$

Here ϵ is the dielectric constant of helium, and n is the electron density. The kernal K_{ij} is obtained from an integration over Bessel functions and is a function of the screening parameter, h/R, while the elements γ_{ij} and g_{ij} are simple expressions. All elements depend on L, and the density enters only through Ω_0.

Volkov and Mikhailov solved a Wiener-Hopf integral equation for the amplitude of the EMP potential. They obtain an explicit expression for $\omega(L)$ in the limits $\omega\tau \gg 1$ and $\omega/\omega_c \ll 1$. This expression is

$$\omega = \frac{L\sigma_{xy}}{\pi\epsilon_0(\epsilon+1)R}[ln(\frac{2R}{\lambda}) - \Psi(L+\frac{1}{2})+1], \quad (3)$$

where $\sigma_{xy} = ne/B$, and Ψ is the digamma function. The penetration depth λ is the maximum of the density profile width at the sample perimeter b or ℓ, which is given for $(\omega_c^2-\omega^2)\tau^2 \gg 1$ by

$$\ell = \frac{ne^2}{m\epsilon_0(\epsilon+1)\omega_c^2} = (\frac{\Omega_0}{\omega_c})^2\frac{R}{\tanh(h/R)}. \quad (4)$$

They find the following expression for the linewidth,

$$\Delta\omega = \sigma_{xy}L/(\epsilon+1)\epsilon_0 R\omega\tau^*, \quad (5)$$

where τ^* is the elastic scattering time in the Drude model in a large field.

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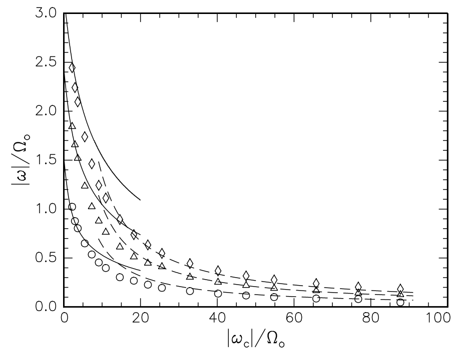

Fig. 1. Normalized plot of ω vs ω_c for L = 1-3, $n = 7 \times 10^7 cm^{-1}$ and $R = 5.4mm$. Solid curve - Fetter's theory; dashed curve - theory of Volkov and Mikhailov.

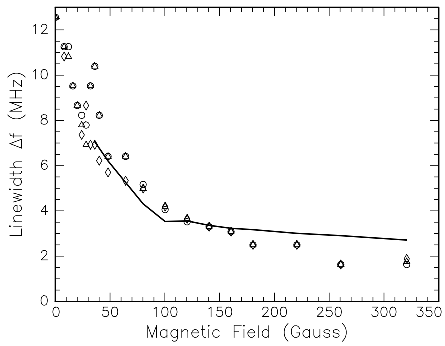

Fig. 2. Linewidth vs B^{-1} for L = 1-3, $n = 1.76 \times 10^8 cm^{-1}$, R = 8.0 mm, and T = 400 mK. The solid line is a qualitative fit to theory.

Our sample cell contains electrons located midway between two capacitor plates into which electrodes are formed. The bottom plate consists of four concentric electrodes. A holding voltage applied to chosen electrodes confines the electron pool above these electrodes. The magnitude of a repelling guard voltage applied to electrodes outside of the electron pool alters the pool radius and determines the density profile at the perimeter. The upper plate includes a center disk and two electrodes along the perimeter of angular width of 12 and 80 degrees. An rf voltage applied to one of these electrodes drives either radial or EMP modes. These electrodes are connected to a transmission line terminated in 50 Ω. We measure the resonant mode frequencies with a swept rf reflection spectrometer.

We define the width of the edge profile b as the separation of radii at which the density is 10% and 90% of that at the center. The density profile was calculated numerically for various guard voltages.

Experimental data for different densities fit on a universal plot of normalized mode frequencies ω/Ω_0 versus normalized cyclotron frequency ω_c/Ω_0 consistent with Eq. (1). A normalized plot of the data for the three lowest modes is shown in Fig. 1. The result of Fetter's theory using a 29×29 matrix in Eq. (1) is given by the solid lines. Volkov and Mikhailov's theory is plotted as dashed lines with $\lambda = b = 0.7mm$.

We show the linewidth as a function of B in Fig. 2. The solid curve shows the qualitative theoretical variation given by Eq. (5) calculated with experimental values of ω.

We have shown that a 29×29 matrix solution to Fetter's equation is sufficient up to $\omega_c/\Omega_0 \approx 100$. The parameter ℓ is equal to b at $\omega/\omega_c \cong 4$. We conjecture that the deviation of the experimental data below Fetter's theoretical prediction at intermediate fields results because for $\lambda < b$ the EMP mode is confined to the reduced density at the sample edges and hence a reduced mode frequency. For the theory of Volkov and Mikhailov, we used $\lambda = b$ although the definition of b is somewhat arbitrary.

The linewidth is nearly independent of mode number, since the factor q/ω is approximately independent of q. The linewidth decreases faster than the predicted dependence on magnetic field at large fields.

In conclusion, the data are in reasonable agreement with the two theories in the regimes where each is applicable. Attempts will be made to take the exact profile into effect in the theory[6].

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