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Experimental investigation of low-frequency edge magnetoplasma modes in two-dimensional sheets of ions trapped below the surface of superfluid helium

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We report the experimental observation of unconventional low-frequency magnetoplasma modes in 2D sheets of ions. Some of them are multipole edge modes of the type predicted to exist by Nazin & Shikin; others have a dependence of frequency on magnetic field similar to that for conventional edge modes and may be related to satellite modes discussed by Ye & Zaremba.

1. INTRODUCTION

Sheets of ions trapped below the surface of superfluid helium are proving ideal for the study of collective excitations of a bounded two-dimensional cold classical plasma, in both the fluid and the crystal phases [1,2]. At temperatures below about 200mK the ions move in a very clean superfluid background, their mobility being limited only by interaction with the helium surface ripplons. Modes of oscillation are therefore lightly damped, so that closely spaced resonances can be easily resolved. In contrast to electrons above the surface of the helium, the ions in the crystal phase are hardly affected by the formation of (anti)dimples on the helium surface. The modes with which we are concerned in this paper lie for the ions in a convenient frequency range (1-100kHz), and interesting effects due to a magnetic field lie in the convenient range of field up to about 4T.

2. RESULTS AND DISCUSSION

The apparatus and the methods of excitation and detection were similar to those reported by us earlier [1]. The positive ion used in our experiments has a effective mass about $30m_4$. The ions were trapped typically 40nm below the surface of superfluid helium midway between two circular electrodes separated by a distance, $2d$, of 3.1 mm. The modes were excited by an oscillating electric field and detected indirectly by their effect, through a non-linear coupling, on the frequency and linewidth of the fundamental axisymmetric magnetoplasma mode, which was driven simultaneously at a frequency of typically 150 kHz.

The spectrum of modes observed at frequencies below 20kHz and magnetic fields below 4.5T is shown in figure 1.

The closed squares correspond to conventional edge magnetoplasmons (EMPs): those with M=0 in the notation of Nazin and Shikin [3]. Such modes were first observed in the electron system [4,5], and a study of them in the ion system was reported in [1]. If proper account is taken of the fact that the charge density falls to zero smoothly over a distance d near the edge of the sheet, extra modes are predicted exist [3]. The observation of these new multipole modes (M=1,2,3,..) in the ion system was reported in [2], and those with M=1 are shown by the closed diamonds in figure 1. The theory [3,6] of the multipole modes was developed for the case of a semi-infinite sheet, the modes being characterized by the integers M and by wavenumbers q along the edge of the sheet. The modes are confined to a distance of order s/ω_c from the edge (s is the speed of propagation of ordinary plasma waves, and ω_c is the cyclotron frequency). The mode frequencies for a circular pool are therefore given approximately by taking $q = m/\left(R_{pool} - s/2\omega_c\right)$, where m is an integer. The resulting theoretical frequencies are shown by the solid lines in figure.1, and we see that there is good agreement with experiment. The open diamonds indicate a mode with M=2; we have observed a more extensive set of M=2 modes in a more dense pool, and again there is good agreement with the theory. The modes with M=1 have also been observed very recently by Kirichek *et al* [7] in sheets of electrons above the surface of liquid helium.

It is interesting that we can excite modes with values of m up to at least 12, in spite of the fact that the experimental cell appears to have circular symmetry, although the excitation of all non-axisymmetric modes does require a large drive. We suspect that the circular symmetry of the pool is slightly broken, perhaps by irregular variations of the contact potential at the electrode surfaces.

Below a temperature of about 62mK the ion pool of figure 1 crystallizes. Shear modes then appear at frequencies up to about 2kHz. They are the subject of other papers at this Conference.

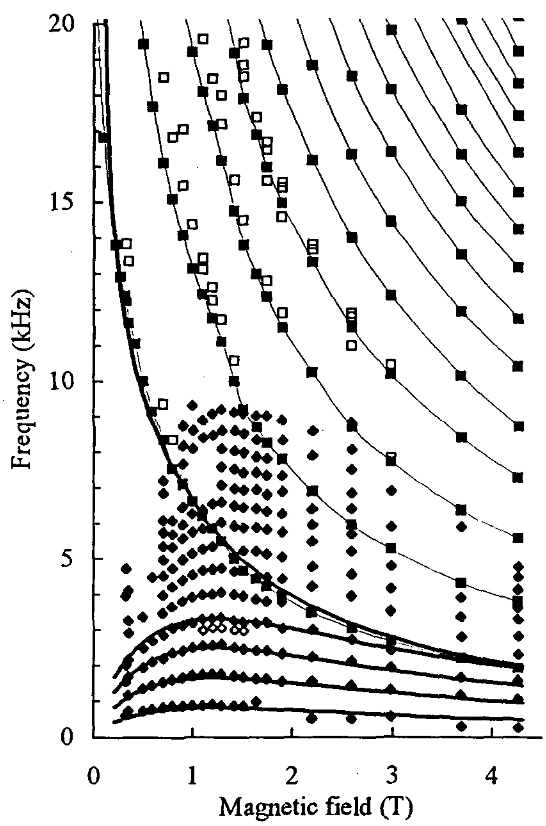

Fig.1. The resonant frequencies of the collective modes of a positive ion pool plotted against magnetic field. Charge density $n = 8.8\text{x}10^8\ \text{m}^{-2}$; pool radius 12.34mm; T=55mK. The thick solid lines are theoretical; see text.

There remain to be discussed the modes indicated by the open squares in figure 1. They have been observed in a number of different pools and in two different experimental cells. Their frequencies vary with magnetic field and pool radius in much the same way as do those of the conventional EMPs. They depend only very weakly on temperature, and they show no observable anomaly at the melting temperature. The strength of these modes is comparable with that of the conventional EMPs when $\omega_c d/s \approx 1$, but it is much weaker at both higher and lower magnetic fields. The modes are not related to other easily excited modes of the pool by any simple harmonic ratios, from which we conclude that they are not instrumental in origin.

As yet we have not been able with certainty to identify these modes with any that have been predicted to exist theoretically. They cannot be related to the "satellite modes" discussed by Ye & Zaremba [8] in the context of anharmonic electron dots, as this approach does not change the total number of modes and does not predict any additional modes. They might be related to those observed in electron sheets above the surface of liquid helium by Kirichek *et al.* [7], and identified by these authors as magnetoripplon modes. It has been suggested by Monarkha [9] that such modes exist if account is taken of the fact that the edge of the pool is not strictly fixed, but we believe that there is a need to examine whether they really exist as separate modes.

3. CONCLUSIONS

Our experiments have shown that a two-dimensional Coulomb fluid or crystal confined to a circular pool in a perpendicular magnetic field can support at low frequencies not only conventional edge magnetoplasmons and shear modes, but also the multipole edge modes predicted to exist by Nazin & Shikin [3] and other low frequency modes which are yet to be identified.

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