Confined Electron Crystals and Rydberg States on Liquid Helium

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Abstract

Experiments are now in progress to try to measure and control the quantum states of surface state electrons on liquid helium, both individually and in arrays, for potential use as qubits [1].

This requires, in the first instance:

- the fabrication of novel electronic devices using microstructured substrates,
- the excitation of the excited Rydberg states using millimetric microwaves,
- the detection of individual electrons and their quantum states.

These are considerable technical challenges. This paper will review general progress in this field and will present experimental results for three particular aspects.

Three terminal microchannel devices have been fabricated on GaAs (with Dr A.Kristensen, Neils Bohr Institute, Copenhagen), where the conduction occurs via free electrons on the surface of suspended liquid helium in 16 micron wide channels, 1.6 microns deep [2]. This device is equivalent to an AC-coupled Field Effect Transistor (FET), with the source-drain current controlled by a gate electrode. The electrons form a conducting strip in the channels about 20 electron spacings across. Above 1 K, these surface-state electrons form an ideal classical non-degenerate Drude 2D conductor. The resistivity is due to scattering from ^{4}He vapor atoms; the system is ohmic and independent of the electron drift velocity. But, below 1 K, strong non-linear effects are observed and the resistance depends with the electron current density and electron drift velocity. We suggest that these effects are due to the spatial ordering of the 2D electrons in the microchannels into a classical Wigner crystal. The moving crystal interacts coherently with ripplons on the helium surface, giving rise to a dynamically ordered, striped phase of current filaments. Oscillations in the resistivity may be due to the formation of discrete ordered lines of electrons along the edges of the channels, as suggested by molecular dynamics simulations.

These surface state electrons can be excited into a series of Rydberg states, or energy levels, in the potential well above the helium surface. The microwave absorption to the first excited Rydberg state near 200 GHz has now been measured below 1 K [3]. The temperature-dependent contribution to the linewidth $\gamma(T)$ agrees well with theoretical predictions and is very small below 700 mK, in the ripplon scattering regime. Absorption saturation and power broadening were observed as the fraction of electrons in the first excited state was increased to 0.49, close to the thermal excitation limit of 0.5. The Rabi frequency Ω was determined as a function of microwave power up to a value of 280 MHz. High values of the ratio $\Omega/\gamma(T)$ confirm this system as an excellent candidate for qubits. Hysteresis effects are observed due to Coulomb interactions between the electrons.

A new electronic trap system for electrons on helium has now been fabricated on silicon (by G.Papageorgiou with Dr Y. Mukharsky, CEA, Saclay, France), incorporating a single-electron-transistor (SET), to detect individual electrons and their quantum states. Preliminary results will be presented.

[1] M.I.Dykman, P.M.Platzman and P.Seddighrad, (2002) in press.

[2] P.Glasson *et al*, Phys.Rev.Lett. 176802 (2001).

[3] E.Collin *et al.* Phys.Rev.Lett. 89, 245301 (2002).