Superflow in amorphous solid helium

In 2004, Kim and Chan observed a superfluid fraction in solid helium. This remarkable discovery extended superfluidity to all three phases of matter - gases, liquids and solids - and created an entire new field of physics [1]. Perfect crystalline helium is not expected to be a superfluid. However, superflow via defects such as vacancies, dislocations or amorphous regions in the solid is predicted. We have created entirely amorphous solid helium in small pore diameter porous media such as MCM-41. Using D20 we have shown that the confined solid has no Bragg peaks and therefore no crystalline regions. Using IN5, we find there are no phonons. This new amorphous quantum solid is an exciting candidate for superflow in solids and neutrons are playing a critical role.

Figure 1: Phase diagram of helium showing the supersolid phase (from reference [2]).

Helium is a simple atom. It has a light mass, 4 nucleons surrounded by two tightly bound electrons in a stable unit. The $^4\text{He}^-^4\text{He}$ interaction is equally simple. Yet at low temperature the atomic de Broglie wavelength is long and helium displays rich and fascinating quantum properties. Below 2 K liquid helium becomes superfluid and flows without friction. Since there is no friction, superfluid helium in a container remains motionless when the container is oscillated, as if it is massless. Indeed the superfluid fraction is determined in this way. Equally, below 2 K, some liquid helium condenses into a single quantum state, denoted Bose-Einstein condensation (BEC). BEC is the driver of superflow.

Under a pressure of 25.3 bar or more, helium solidifies. Atomic diffusion is rapid and the solid anneals readily into one or a few large single crystals. Remarkably, in 2004 superflow in solid helium was reported [2]. Below a temperature of 0.2 K, a fraction of the solid ceased to oscillate in an oscillator exactly as the liquid. There is a supersolid phase (see figure 1). However, like superconductivity in the copper oxide and iron base superconductors, the mechanism of this superflow remains a mystery.

Although supersolidity is now confirmed in several laboratories, the observed fraction that is superfluid varies dramatically, from 0.015 to 20 % depending upon how the solid is prepared. This suggests that the superflow is via defects, vacancies, dislocations, grain boundaries or amorphous regions in the solid. Interestingly, the shear modulus of solid helium also increases with decreasing temperature exactly as the superfluid component. This suggests that the two are related and both dependent on the mobility of defects or dislocations. Equally interesting, path integral Monte Carlo calculations predict a large superfluid fraction and BEC in amorphous solid helium.
We have created amorphous solid helium by confining it in porous media. If the pore diameter is less than 50 Å, the solid is entirely amorphous. Helium is highly attracted to the rough pore walls. When helium first enters the pores, it forms an amorphous layer on the walls. Subsequent solid helium grows as an amorphous solid away from the walls. If the pore diameter is small enough the pores are filled entirely with amorphous solid. Using the instrument D20 we have measured the static structure factor, S(Q), of liquid and solid helium in 34 Å diameter gel sil and in 47 Å diameter MCM-41. As shown in Figure 2, the static structure factor, S(Q), of solid helium at lower temperature (T < 1.1 K) is very similar to that of the liquid at higher temperature (T > 1.8 K). No Bragg peaks, characteristic of a crystal, are observed in the solid. In addition we have measured the excitations of the amorphous solid on the instrument IN5. No phonons characteristic of a crystalline solid are observed. Rather, the dynamic response is spread over a wide energy range quite different from the crystalline solid. Analysis of this data is in progress.

In summary, we have shown that amorphous solid helium can be made. This opens a path to demonstrating whether superflow is indeed possible via amorphous helium. Equally we can test whether amorphous solid helium shows BEC. In addition the dynamics of a highly quantum amorphous solid can be investigated for the first time. Superflow in solid helium remains a fascinating field and neutrons are playing a critical role in discovery.

**REFERENCES**

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