High-quality helium crystals show supersolid behavior

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High-quality, single-crystal, ultra-cold solid helium exhibits supersolid behavior, suggesting that this frictionless solid flow is not a consequence of defects and grain boundaries in poor-quality, polycrystalline, solid helium, according to a team of Penn State researchers.

In 2004, Penn state physicists -- Eunseong Kim, then-graduate student and Moses Chan, the Evan Pugh professor of physics-- announced the observance of frictionless superflow in solid helium at nearly absolute zero. This new phenomenon is a cousin of Bose-Einstein condensate observed in gases in 1995 and in liquid helium in 1938.

Since then, their results have been replicated at the University of Tokyo, Keio University, Japan, and Cornell University. While the experiment was duplicated at Cornell, one experiment there found that if the solid helium was annealed – cooled slowly from the melting point – the supersolid behavior disappeared. This suggested that the theoretical idea of supersolidity is possible only in poor-quality solid helium and that the superflow is due to defects in the poorly grown crystals.

To create solid helium, the gaseous helium must be cooled very close to absolute zero and put under at least 25 atmospheres. Unlike other gases, helium remains a liquid at ambient pressure all the way down to absolute zero. Determining that the solid helium acts as a supersolid or Bose Einstein condensate is tricky. In a Bose-Einstein condensate all the atoms are at the lowest possible energy state, and they all behave in unison. The supersolid portion of the crystalized helium appears to flow without friction. For liquids and gases, this idea is less difficult because the atoms of both move around more and can easily slide past each other. But, in a solid, especially a very cold one, atoms do not usually flow easily or without friction.

The researchers relied on inertia to determine that the ultra-cold solid helium had a supersolid component. They did the high-pressure cooling experiment in a tiny torsional oscillator, a pendulum-like setup. Liquid helium, under pressure, entered a small chamber at the end of a thin rod. The liquid then cooled to the solid phase and the torsional oscillator was set at a specific frequency.

With a normal solid, the total mass of the sample would dictate the force required to move the oscillator at a specific frequency and as long as the mass remained the same, the same force would be required to keep the system at the same frequency . In Chan and Kim's experiment, when the temperature went below 0.2 degrees Kelvin, the frequency abruptly increased, indicating that some of the solid helium was not moving with the chamber or with the rest of the solid. "At about 25 atmospheres, the initial pressure we investigated, 1 percent of the helium becomes a supersolid," says Chan. "This supersolid fraction becomes frictionless, allowing the rest of the helium to 'flow' past it."

Cornell, in duplicating this experiment used multiple experimental cells, and in one, the annealing process eliminated the supersolid effect. Tony Clark, graduate student in physics is following up on Kim's experiment to test the Cornell findings.

"All solid samples studied to date were made by the so-called blocked capillary method which tends to make poor quality crystals," says Kim. Clark made a new torsional oscillator that allows the growth of solid helium of extremely high crystallinity. The new solid helium is grown from the superfluid phase by keeping the sample cell at the temperature and pressure boundary where both solid and liquid helium coexist. As more helium is very slowly fed into the chamber, a helium crystal grows from the superfluid.

"This constant pressure growth is indeed the preferred method of many prior experiments in growing single crystals," says Chan.

These high quality crystals do exhibit supersolid response, but the supersolid percentage is smaller at only about .3 percent rather than 1 percent.

In another experiment, Chan's team tested the expected result of increased pressure on the solid helium to determine the pressure at which supersolid behavior disappears. Kim and Chan extended the experiment up to 130 atmospheres and found the supersolid portion decreases with pressure from 60 atmospheres and higher. The researchers extrapolated the decreasing fraction and determined that at or near 170 atmospheres the supersolid portion will disappear. "However, they have not carried the experiment to check this extrapolation because the sample cell exploded," says Chan.

Source: Penn State

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