Superfluid helium-4 whistles just the right tune

January 28 2005

University of California, Berkeley, physicists can now tune in to and hear normally inaudible quantum vibrations, called quantum whistles, enabling them to build very sensitive detectors of rotation or very precise gyroscopes.
A quantum whistle is a peculiar characteristic of supercold condensed fluids, in this case superfluid helium-4, which vibrate when you try to push them through a tiny hole. Richard Packard, professor of physics at UC Berkeley, and graduate student Emile Hoskinson knew that many other researchers had failed to produce a quantum whistle by pushing helium-4 through a tiny aperture, which must be no bigger than a few tens of nanometers across - the size of the smallest viruses and about 1,000 times smaller than the diameter of a human hair.

To their surprise, however, a chorus of thousands of nano-whistles produced a wail loud enough to hear. This is the first demonstration of whistling in superfluid helium-4. According to Packard and Hoskinson, the purity of the tone may lead to the development of rotation sensors that are sufficiently sensitive to be used for Earth science, seismology and inertial navigation.

"You could measure rotational signals from an earthquake or build more precise gyroscopes for submarines," Packard speculated.

Four years ago, Packard and his coworkers built and successfully tested a gyroscope based on quantum whistling in superfluid helium-3. But that required cooling the device to a few thousandths of a degree above absolute zero, a highly specialized and time-consuming process. Because the new phenomenon exists at 2 Kelvin - a temperature achievable with off-the-shelf cryo-coolers - the proposed sensors also will be user-friendly to scientists unfamiliar with cryogenic technology. A temperature of 2 Kelvin is the equivalent of minus 456 degrees Fahrenheit.

"Because these oscillations appear in helium-4 at a temperature 2,000 times higher than in superfluid helium-3, it may be possible to build sensitive rotation sensors using much simpler technology than previously believed," the researchers wrote in a brief communication appearing in the Jan 27 issue of the journal Nature.

Packard noted that sensitive rotation or spin detectors could have application in numerous fields, from geodesy, which charts changes in the spin and wobble of the Earth, to navigation, where gyroscopes are used to guide ships. Though little is now know about the rotational signals from earthquakes, having a sensitive rotation detector might reveal new and interesting phenomena.

Quantum whistling is analogous to a phenomenon in another macroscopic quantum system, a superconductor, which develops an oscillating current when a voltage is applied across a non-conducting gap. Nobel Laureates Philip Anderson, Brian Josephson and Richard Feynman predicted in 1962 that the same would happen in superfluids. In the case of superfluids, however, a pressure difference across a tiny hole would cause a vibration in the superfluid at a frequency - the Josephson frequency - that increases as the pressure increases. The fact that the fluid oscillates back and forth through the hole rather than flows from the high-pressure side to the low-pressure side, as a normal liquid would, is one of the many weird aspects of quantum systems like superfluids.

Eight years ago, Packard and fellow UC Berkeley physicist Seamus Davis, now at Cornell University, heard such vibrations when pushing superfluid helium-3 through a similar array of 4,225 holes, each 100 nanometers across. Though no simple feat - it took them 10 years to make their experiment whistle, working at one thousandth of a degree Kelvin - it's theoretically easier than with helium-4.

For helium-4 to whistle, physicists predicted that the holes either had to be much smaller, pushing the limits of today's technology, or the temperature had to be within a few hundred thousandths of a degree of the temperature at which helium-4 becomes a superfluid, that is, 2 Kelvin. While working with an array of holes 70 nanometers across, essentially testing the apparatus with helium-4 before using it to conduct a helium-3 experiment, Hoskinson was surprised when he put on earphones and heard the characteristic pennywhistle sound as the pitch dropped with the pressure in the device.

"Predictions on where the Josephson oscillations would occur put them much closer to the transition temperature than I could hope to go," Hoskinson said. "The fact that I could detect the oscillations with the set-up I had was amazing in itself, and something we're very interested in exploring."

He and Packard calculated that the tones were due to a different mechanism, phase slippage, than that producing the whistle in helium-3, though it follows the same relationship between frequency and driving pressure. Phase slippage shouldn't have produced a pure tone at all. The vibrations at the holes should shift randomly and get lost in the noise. Even if phase slippage did produce a constant tone in a single hole, the whistles from the array of 4,225 holes should have been out of phase and the resulting sound less than 100 times louder than that from a single hole.

Apparently, Packard said, the vibrating holes somehow achieved synchrony, like crickets chirping in unison on a summer evening, amplifying the sound 4,000 times higher - loud enough to be heard above the background noise of the experiment.

"For 40 years, people have been trying to see something like this, but it has always been with single apertures," Hoskinson said. "Maybe it's true that you don't get coherent oscillations with a single aperture, but somehow, with an array of apertures, the noise is suppressed and you hear a coherent whistle."

"There was no reason to expect that. I still think it's amazing," Packard added.

The research by Packard, Hoskinson and post-doctoral fellow Thomas Haard is supported by the National Science Foundation and by the National Aeronautics and Space Administration.

Quantum whistle
Hear the synchronized vibrations from a chorus of more than 4,000 nano-whistles, created when physicists pushed superfluid helium-4 though an array of nanometer-sized holes. Note that the pitch drops as the pressure drops.

Source: University of California, Berkeley (By Robert Sanders) provided for information purposes only.