Oscillation Frequency Dependence of Non-classical Rotational Inertia of Solid ^{4}He

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Recommended with a Commentary by P.W. Anderson, Princeton University.

Theorists have been urging that the experimenters in the field of NCRI (non-classical rotational inertia) in solid ^{4}He—more widely known as "supersolidity"—should try to alleviate the confusion in the subject by varying only one variable at a time. Specifically, they have been advocating variation of the torsional oscillator frequency without changing samples, since it is argued that the dissipation peak which accompanies the phenomenon will occur when this frequency roughly matches the relevant relaxation rate. Since relaxation rates usually vary with temperature one may get a hint as to what the relaxation process is.

Kojima et al have now ingeniously carried out this simple and crucial test by using a cell with two resonant frequencies differing by a factor 2.4 but the same sample chamber. There is a distinct shift to higher temperature at higher frequency: there also is a poorly-understood *decrease* of the dissipation peak. We will discuss in a moment the striking hysteresis effects also observed at low temperatures.

There are two general classes of suggested explanations for the NCRI phenomenon. Relatively straightforwardly, we may assume the solid has a superfluid component, whch rejects vorticity at low temperature and low rotational velocity. The dissipation is caused by the viscous resistance to vorticity motion into and out of the sample as the rotational velocity oscillates. The vortices move more quickly at higher temperatures, explaining the sign of the effect.

A second suggestion is not completely distinct from the above: that there is somehow a percolating network of defects such as dislocations, grain boundaries, etc—a network of superleaks—but these again will relax by phase slip, which is equivalent to vortex motion. A question which strikes one is “where does superflow stop?” in the neighborhood of the defect, for example.

Various “glassy’ or defect models not involving superfluidity—e g motion of dislocations-- have been proposed. To us it is not clear how they explain the observations so we cannot predict a sign of the shift for them.

Another significant observation was that in studying the vibrational amplitude dependence of the effect as a function of frequency, the authors could show that the relevant variable is the maximum velocity of the solid, not the displacement or the acceleration: a critical velocity is what is necessary to suppress the effect. This too argues for the superfluid nature of the phenomenon.

Most intruguing was the unexpected observation of a large hysteresis effect at low temperatures, <40 mdeg. The curve of NCRI vs drive velocity is reversible at higher T’s, but if the drive is reduced to zero around 15 millidegrees and the system allowed to ring down, when the drive is now increased *at the low temperature,* the moment of inertia defect remains up to quite high amplitudes, amplitudes at which, if cooled with drive on, one would observe almost no NCRI : *the missing vorticity does not reenter the sample.* As the sample is then warmed with the drive on through about 30-40 mdeg, the moment of inertia relaxes to the classical value.

This phenomenon is compatible with the idea that there is an actual supersolid phase transition occurring at a Tc of tens of millidegrees, and not with much else. On the other hand, we cannot necessarily deduce that the sample showing the phase transition is a perfect single crystal, in view of the large annealing effects seen by others: there is a Tc, but it may be structure sensitive. Nonetheless, the range of possibilities has been much reduced by these experiments.

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