Can Helium-4 Transition to a Supersolid?

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For forty years supersolid behavior has been predicted, and since the 1970s, theories about supersolid behavior involving helium-4 have been developed. However, it wasn't until 2004 that some evidence of supersolid behavior was found. But, when a group of scientists from the Helsinki University of Technology tested the thermodynamical properties of solid helium-4, they found something different.

"We found some unexpected behaviors in entropy at low temperatures," Igor Todoshchenko, one of the experimenters, tells *PhysOrg.com*. "This is an anomaly that no one thought of." The results of the experiment are published in an article titled "Melting Curve of 4He: No Sign of a Supersolid Transition down to 10 mK" in *Physical Review Letters*.

"In solid helium-4," explains Todoshchenko, "the absences of atoms — called vacancies — are very mobile and delocalized, being the property of the whole solid. At very low temperatures, the idea was that they may condense to form a superfluid." He pauses before continuing. "If you think about the motion of the vacancy system in one direction, then the mass of the solid is moving in the opposite direction, which means that crystalline solid moves without friction. The solid behaves like a superfluid. This is the theoretical prediction that many people have tried for years to find."

And, while this was thought to have been achieved in 2004, through observation of supersolid-like characteristics, the mechanism was not understood, and no knowledge of how the helium-4 supersolid was formed came out of it. "We started to investigate the behaviour of entropy of the [helium-4] solid by measuring its melting pressure," Todoshchenko says. "Entropy can be used to verify theoretical models of solid. In particular, it should drop at the supersolid transition."

And what did the Helsinki University of Technology team find when they began to measure the entropy of solid helium-4? "It is not behaving as predicted by classical model of solid," Todoshchenko explains. "Below the temperature 0.1K, the entropy stopped decreasing with decreasing the temperature. It stayed constant. This is a deviation from classical behavior."

Todoshchenko does not rule out the possibility of a helium-4 supersolid, however. "What does this mean? We do not see a drop of the entropy at the supposed supersolid transition, but we see that it stays constant, probably indicating some low-energy degrees of freedom in solid. Maybe that it isn't connected to a supersolid, maybe it is something else. Or maybe it is supersolid, but its nature is more complicated than thought before." He points out this anomaly requires further study: "We are interested in this anomaly because it is not what anyone expected… Our accurate measurements of the entropy of the solid show there is some different system, consisting of defects, or impurities, or something we don't know."

In order to improve their knowledge of the properties of solid helium-4 at low temperatures, the Helsinki team plans to run experiments with different concentrations of helium-3 impurities. "Our findings might be related to impurities," Todoshchenko suggests. "We will do this measurement again, but with ultra-pure helium-4, and we will compare the results with what we measured in helium-4 of commercial purity. If the anomaly is present also in ultra-pure helium-4, it is not connected to impurities but it is intrinsic property of solid helium-4."

For now, the findings in Helsinki seem to indicate that there is no transition in a helium-4 solid to a supersolid. But the search for a new quantum phase of matter continues. “We will keep working on this,” Todoshchenko says. “Our measurements could give a better idea of what is solid helium-4 at low temperatures, a better understanding of the characteristics of what might make a supersolid.”

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