Extra-large 'atoms' allow Penn physicists to solve the riddle of why things melt

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Physicists at the University of Pennsylvania have experimentally discovered a **fundamental principal about how solid materials melt**. Their studies have shown explicitly that melting begins at defects within the crystalline structure of solid matter, beginning along the cracks, grain boundaries and dislocations that are present in the otherwise orderly array of atoms. Their findings, which will appear today in the journal *Science*, answer longstanding fundamental questions about melting and will likely influence research in physics, chemistry, materials science and engineering, as well as studies of biological importance.

"Melting is one of the most fundamental phenomena in physics and is one of the phase transitions most frequently seen in daily life," said Arjun Yodh, a professor in Penn's Department of Astronomy and Physics. "Yet major details about the mechanisms that drive the melting of an ice cube are missing. Superficially, the principle is straightforward. As a solid heats up, molecules within the ice acquire more energy and jiggle around more, driving the transition from a solid to a liquid. This is true in part, but reality is richer and more complex."

In the Science paper, the Penn physicists show direct evidence for a leading theory of melting, the notion that the start of melting – premelting – occurs at imperfections in the orderly structure of solid crystals. Premelting occurs in areas where the alignment of atoms is not perfect, especially at the boundaries within crystals where the patterns of atoms shift much like imperfections in the grain of a piece of wood.

One problem with proving theories of how things melt is size; one simply cannot see the atoms in a solid structure as it melts. Not only are the atoms very small, but the solid matter tends to obscure what goes on inside. To get around these problems, Yodh and his Penn colleagues made atoms bigger.

"We created translucent three-dimensional crystals from thermally-responsive colloidal spheres. The spheres are like small beads visible in an optical microscope," said Ahmed Alsayed, a doctoral student in the Department of Astronomy and Physics and lead author of the study. "The spheres swell or collapse significantly with small changes in temperature, and they exhibit other useful properties that allow them to behave like enormous versions of atoms for the purpose of our experiment."

As they raised the temperature of the colloidal particle crystal, the researchers could record changes within the crystal by following the motions of many individual spheres using a microscope and a video recorder.

"When we raised the temperature, we could track the vibrational movement of the spheres," Alsayed said. "Premelting was first revealed as an increased movement along the lines of defects in the crystal. These motions then spread into the more ordered parts of the crystal. We could see that the amount of premelting depended on the type of crystal defect and on the distance from the defect."

The researchers believe these observations will lead to a better understanding of the melting process and enable more quantitative predictions of just how a substance might melt.

"The existence of premelting inside solid materials implies that liquids exist within crystals before their melting temperature is reached," Yodh said. "Understanding this effect will provide insight for the design of strong materials that are more or less impervious to temperature changes and could also apply to our theories of how natural materials, such as water, evolve in our environment."

Other Penn researchers involved in this study are Mohammad Islam, Jian Zhang, and Peter Collings, who is also a professor of physics at Swarthmore College.

Source: University of Pennsylvania

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