Pulsed Power
Extreme environments

Pushing Water to the Limit: *Ultrafast Solidification in the Sandia Z Machine*

Pulsed magnetic compression can be used to examine extremely rapid phase transitions.

For more information:

Technical Contact:
Daniel Dolan
505-284-8608
dhdolan@sandia.gov

Science Matters Contact:
Alan Burns, Ph.D
505-844-9642
aburns@sandia.gov

The formation of ice by cooling water is slow because ice crystals must first be nucleated on a "seed." However, by using compression at extremely high pressures rather than cooling, seeding is not required and solidification conditions can be rapidly created in water. This allows us to study the fundamental time scales of the phase transition.

Water can exist in many different solid forms at extreme pressure. Above 2 GPa (approximately twenty thousand atmospheres), water becomes ice VII, a dense solid stable beyond 300 K. To reach these states, researchers at Sandia utilize isentropic compression techniques to bring water to extreme pressures while maintaining moderate temperature. As shown in Figure 1, isentropic compression of liquid water enters the ice VII region near 3 GPa. Interestingly, solidification still does not instantly occur at this pressure unless a nucleating seed is present.

Using pulsed magnetic compression in the Sandia Z machine, small water samples (about 3 mg) at atmospheric pressure are squeezed up to 10 GPa in approximately 200 ns. Rapid solidification does occur under these conditions, and is studied by tracking the water sample interface with an optical interferometer. A smooth, continuous motion of the interface during compression indicates a liquid phase; when the transformation to solid water occurs, there is an abrupt, discontinuous motion. Ultra-pure water shows liquid-like behavior until the pressure reaches approximately 7 GPa. At higher pressures, water contracts in just a few nanoseconds and solidifies as indicated by the discontinuous motion in the interferometer. Experiments with different container materials yielded identical results, suggesting that solidification occurs throughout the compressed water sample, not simply at the water-container boundary.

This work reveals that 7 GPa is the experimental limit to isentropic compression of liquid water, information critical in the study of dynamic material behavior. It is also significant that the time scales probed in this work approach the domain of molecular dynamics, thus providing a potential benchmark for numerical simulations of solidification.

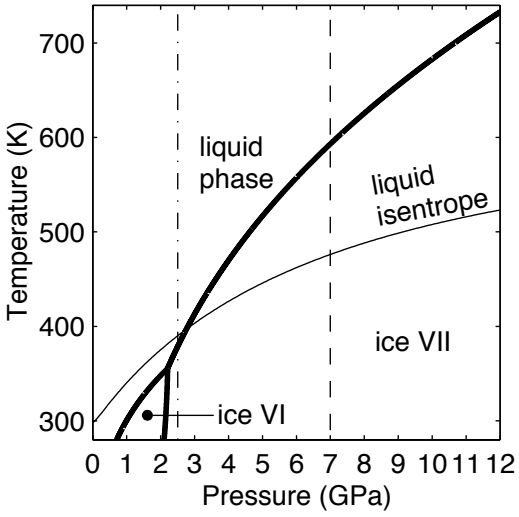

Figure 1: Heavy lines indicate the boundaries between different forms of water. The solid line shows the temperature-pressure path of liquid water under isentropic compression, which crosses the ice VII boundary near 3 GPa (left dashed line). Ultrafast solidification is observed at 7 GPa (right dashed line).

Sandia National Laboratories

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