Probing the Metastability Limit of Liquid Water under Dynamic Compression

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Water Phase Diagram

- Equilibrium phase boundary
- “Kinetic” phase boundary (illustrative)

Ramp Compression Omega Experiment

- Freezing
- Ice VII
- Metastable Liquid
- Liquid

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The metastability limit of liquid water undergoing compressive freezing into ice VII is at least ~30% higher than previously reported

- Significant deviations from the equilibrium phase diagram are seen in dynamic compression experiments*
  - Water can remain liquid in a metastable state beyond the liquid-ice VII equilibrium phase boundary**

- We ramp compressed water into ice VII at rates of 0.3 – 3 GPa/ns at the Omega laser facility

- The freezing pressure increases with compression rate to 9 GPa, which is 30% higher than the freezing pressure in Z and Thor experiments at 30x lower compression rates**

- Simulations using the SAMSA kinetics code corroborate the experimental results

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**D. H. Dolan et al., Nat. Phys. 3, 339-342 (2007);
  E. J. Nissen and D. H. Dolan, J. Appl. Phys. 126, 015903 (2019);
Collaborators


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Laboratory for Laser Energetics
The metastable limit of liquid water under ramp compression was previously measured to be 7 GPa at the Sandia Z facility.*


Motivation

The metastable limit of liquid water under ramp compression was previously measured to be 7 GPa at the Sandia Z facility.*


SAMSA kinetics code reproduces experimental data using classical nucleation theory when including:
(1) transient nucleation and (2) separate solid and liquid temperatures**

The metastable limit of liquid water under ramp compression was previously measured to be 7 GPa at the Sandia Z facility*

**Water Phase Diagram**

- **Motivation**

  Is the metastability limit higher than 7 GPa?

  We will investigate the liquid-ice VII phase transition at 10x higher compression rates

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Water was ramp compressed using a reservoir release technique* at the Omega laser facility

- Technique has been characterized to ramp compress solids (Al, Fe, Si)* – first time being applied to water
- Well-defined ramp to ~15 GPa over short ~10-20 ns time scales

Water Target

Omega EP Laser
4-ns square 550 J

1.8 mm

Br-CH reservoir (170 µm)
Vacuum gap (300 µm)

Water cell

Baseplate (30-150 µm)
Sapphire or Aluminum

12% Br dopant acts as preheat shield

Witness

VISAR

VISAR

Witness Window

Al coat

Water layer of interest (10-25 µm)

*Reservoir release technique
The liquid-ice VII freezing pressure was detected \textit{in situ} using VISAR

VISAR: velocity interferometer system for any reflector
The liquid-ice VII freezing pressure was detected *in situ* using VISAR.

VISAR: velocity interferometer system for any reflector
The measured freezing pressure increases with compression rate to 9 GPa

The diagram shows the water phase diagram with temperature on the y-axis and pressure on the x-axis. The freezing pressures for Ice VI, Ice VII, liquid, and Ice VII at different pressures are marked. The isentrope is also indicated.

The equation for the freezing pressure is given as:

$$\eta = \frac{P_{\text{freeze}} - P_{2.2\text{GPa}}}{t_{\text{freeze}} - t_{2.2\text{GPa}}}$$

The data points for different materials are plotted on the graph:
- Sapphire (Omega)
- Quartz (Omega)
- Sapphire (Z)
- Sapphire (Thor)

The text mentions:
- The measured freezing pressure increases with compression rate to 9 GPa.
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\[ \eta = \frac{P_{\text{freeze}} - P_{2.2 \text{GPa}}}{t_{\text{freeze}} - t_{2.2 \text{GPa}}} \]

Simulations using the SAMSA kinetics code* predict the ice VII phase transition close to the experimental observation

- The pressure drive on the baseplate was determined through an optimization technique using the measured witness velocity for the individual shot**


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<table>
<thead>
<tr>
<th>Shot</th>
<th>29419</th>
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<tr>
<td>Sapphire baseplate</td>
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<td>146 µm</td>
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<tr>
<td>Water</td>
<td>13 µm</td>
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<tr>
<td>Sapphire Window</td>
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Summary/Conclusions

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  - Water can remain liquid in a metastable state beyond the liquid-ice VII equilibrium phase boundary**

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