Role of Hydrogen Fractionation in ICF Ignition Target Designs

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Summary

Isotopic hydrogen (H/HD/D) fractionation has been observed in the laboratory but at levels that do not impact ignition target performance.

- Experimental data has demonstrated that fractionated fusion fuels do not exhibit complete solidification.
- Levels of fractionation are not affected by the duration of the layering procedure.
- Current experimental estimates place the degree of fractionation at no more than 10%. Two-dimensional simulations indicate that target performance is unaffected by levels of fractionation less than ~30%.
Slow solidification produces the smoothest deuterium ice layers but increases the possibility of fractionation in D₂-DT-T₂ mixtures.

During solidification:
- \( T = 19.78 \) K
- \( T = 19.83 \) K
- \( Q = 13 \) μW
- Liq. D₂-DT-T₂

Resulting ice layer (if fractionation occurs):
- T₂ rich
- DT rich
- D₂ rich

Boundary condition: \( T = 19.05 \) K

### Triple point

<table>
<thead>
<tr>
<th>Triple point</th>
<th>Vap. press. (Pa) at 19.79 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₂ = 18.72 K</td>
<td>2930</td>
</tr>
<tr>
<td>DT = 19.79 K</td>
<td>2200</td>
</tr>
<tr>
<td>T₂ = 20.62 K</td>
<td>1580</td>
</tr>
</tbody>
</table>
An inner crust of solid deuterium denies the hot spot of the necessary tritium, which, in absentia, can preclude ignition.
A polar cap fractionation scenario exempts the DT-poor poles from the ignited burn wave.
The $\text{H}_2/\text{HD}/\text{D}_2$ fractionation test bed is used to measure the IR absorption coefficient in the solidified mixture.

Experimental Setup

Low-vibration cryostat

Vacuum chamber

Scanning optics

Flip-in viewing system

Pb:salt laser
A mixture does not have a specific triple point but exhibits a first-freezing temperature and solidifies over a range.

\[ \theta = \sum_i m f_i \times T_{tp, i} \]

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Triple point (K)</th>
<th>Mass fraction from pressure</th>
<th>Mass fraction from mass spec.</th>
<th>Mass fraction with frozen D$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$</td>
<td>13.96</td>
<td>0.24</td>
<td>0.26</td>
<td>1/3</td>
</tr>
<tr>
<td>HD</td>
<td>16.60</td>
<td>0.49</td>
<td>0.50</td>
<td>2/3</td>
</tr>
<tr>
<td>D$_2$</td>
<td>18.73</td>
<td>0.25</td>
<td>0.24</td>
<td>0</td>
</tr>
<tr>
<td>First-freezing temperature (K)</td>
<td>16.49</td>
<td>16.42</td>
<td>15.72</td>
<td></td>
</tr>
</tbody>
</table>

- Experimentally, the first-freezing temperature for the mixture was 16.53 K and the mixture had completely frozen at \(~16.10\) K.
- This implies that complete fractionation does not occur in the mixture.
The absorption coefficient of the H$_2$ in the H/D mixture is less than 1/20th of that for pure D$_2$. 

Transmission coefficient

- Pure H$_2$
- Ice sample
- Pure D$_2$
Isotopic hydrogen (H/HD/D) fractionization in solution has been observed in the laboratory at levels approaching 10%.
Fractionization levels in excess of ~30% are required before ignition target performance is affected.
Summary/Conclusions

Isotopic hydrogen (H/HD/D) fractionation has been observed in the laboratory but at levels that do not impact ignition target performance.

- Experimental data has demonstrated that fractionated fusion fuels do not exhibit complete solidification.

- Levels of fractionation are not affected by the duration of the layering procedure.

- Current experimental estimates place the degree of fractionation at no more than 10%. Two-dimensional simulations indicate target performance is unaffected by levels of fractionation less than ~30%.