Sound velocities and absurd optical properties of deuterium

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ITP — 11 Jan. 2001
Acknowledgements

- Marvin Ross
- Bill Nellis
- Erv See, Jr.
- Erikk Ojala
- Keith Stickle
- Steve Caldwell
- Leon Raper
- Walter Hall
- Marina Bastea
Overview

- Reviewing temperature measurements
- Sound velocity measurements on the Hugoniot
- Unexplained optical emission data at 11 GPa
- What’s next
Double shock temperature measurements were key to new hydrogen models

- Optical pyrometry was used to determine temperature from radiance of shock front and D$_2$-Al$_2$O$_3$ interface.

- Previous model which matched all Hugoniot and reshock data (Ross, Ree, Young, 1983) did not do well on reshock temperatures.

- Reshock temperatures were as much as 2000K below prediction.
Ross dissociation model matches data; implies large compression on Hugoniot.
QMC, MD calculations and experiment do not agree at 100 GPa

Quantum Monte Carlo (*) and Molecular Dyn simulations (+) agree in predicting a smaller compression than found in recent Nova expts.

(*) B. Militzer, R. Pollock, Phys. Rev. E 2000,
Sound velocity is a sensitive measure of dissociation in D₂

- Dissociation is small on Hugoniot at two-stage gun limiting pressure
- Hugoniot EOS is insensitive to small dissociation
- Large compressions are seen in laser-driven experiments consistent with Ross’ dissociation model
- Sound speed is a sensitive detector of small changes in compressibility

\[ c^2 = \left( \frac{\partial P}{\partial \rho} \right)_s \]
Experimental method is identical to optical pyrometry

- 6-channel fiber bundle collects emission from shocked deuterium

- Absolute radiance is measured in the six channels at 340, 400, 450, 506, 598, 700 nm bands (40 nm bandpass) with 2 ns time resolution

- No effects of moving shock front for correct time dependence

- Thin impactor is used to generate overtaking rarefaction wave moving at longitudinal sound velocity

- Samples are condensed from ultra-pure $D_2$ gas at 20K
Graphic analysis is used to find sound velocity.

In the graph:
- **position** is plotted on the y-axis.
- **time** is plotted on the x-axis.
- The shock front is indicated by a solid line.
- Interfaces are shown by a dotted line.
- Rarefaction is indicated by a dashed line.
- The labels **D2**, **Al**, and **c from EOS** are used to mark specific points or regions.
- The symbol **Δt** represents the time interval between two events.
Optical emission easily detects rarefaction arrival

- short rise time indicates short optical depth
- plateau region typical of steady wave
- late time peak due to reflection of shock off window
Sound velocities in D₂ under shock compression confirm dissociation model

These data provide a consistent link between gas gun and laser driven Hugoniot EOS measurements in the context of dissociation models.
Data at pressures above 19 GPa is “ideal”
Time response at P < 19 GPa are anomalous

D2 Pyro #15  19 GPa

overtake @ + 280 ns
Optical emission data for $13 < P < 19$ GPa ($3000 < T < 4000$ K) indicates decrease of opacity

- Overtaking rarefaction is observable behind shock front
- Slow rise time indicates long optical depth: unusual rise
- Optical depth varies with wavelength
Emission data at 16 GPa show strong wavelength dependence.
Emission data at lower pressures is highly unusual

- Fast rise time indicates short optical depth
- Arrival of rarefaction wave causes emission intensity to increase!
- Short intense pulse of light at entry into fluid is of unknown origin

Graph showing photomultiplier signal over time at different channels with an indication of rarefaction arrival at Al/D₂ interface.
“low-pressure” optical properties may be due to molecular effects

- *Something* is absorbing light!
- Opacity at $P > 16$ GPa consistent with measured conductivity
- Opacity at low $P$ can’t be electrons based on $\sigma$
- Wavelength dependence inconsistent with simple electron conductivity
- Is this a hint of clusters?

\[
\delta = \frac{2}{\sigma \sqrt{\mu}}
\]

![Graph showing optical properties](image)
These states test hydrogen properties near Jovian surface
We need more sophisticated experiments and theory

- Understanding will be greatly enhanced by using experiments that test the underlying physics.
  - Raman spectroscopy
  - Emission/absorption spectroscopy
  - Optical experiments off the Hugoniot (if we can find a suitable window!)
  - Look for the PPT! — a test of chemical models

- Impact experiments need to continue at high P using magnetic projectile drive (Sandia) and lasers

- Theory has to feature larger simulations that converge at even lower temperatures, and models that include more physics.