Conductivity of multi-shock compressed deuterium

Deuterium Conductivity

Theory (Isentrope)

Theory (Hugoniot)

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Summary

• Deuterium was multi-shock compressed up to 570 GPa

  • Simultaneous velocimetry and emissivity measurements
  • Electrical conductivity inferred from optical absorbance and reflectance measurements
  • Substantial increase observed to metal-like conductivity
Motivation: Jupiter’s B-field is generated by currents in high pressure hydrogen
Experiment: A thin cryogenic D$_2$ layer was compressed by multiple laser-driven shocks at the OMEGA facility.
The D$_2$ layer was characterized by simultaneous velocity, reflectance, and pyrometric measurements.

**Diagram:**
- **OMEGA Laser drive:**
  - Intensity (TW/cm$^2$) vs. time (ns)
  - Key time points: 49 J, 125 J, 467 J

- **Velocity interferometer (ch.1):**
  - Shocked D$_2$ attenuates signal reflected from Al
  - D$_2$ reflectivity increases at 3$^{rd}$ shock arrival

- **Velocity interferometer (ch.2):**

- **Streaked optical pyrometer (SOP):**
  - Time vs. intensity (t ns)
Velocity, reflectance and temperature histories

**Interface Velocity**
- ch1
- ch2

**Reflectivity and Temperature**
- Shocked D$_2$ attenuates signal reflected from Al
- D$_2$ reflectivity increases at 3$^{rd}$ shock arrival

**Velocity interferometer (ch.1)**
- Streaked optical pyrometer (SOP)
Pressure is inferred using EOS tables and imposing continuity at LiF-D$_2$ interface.

*Using Kerley2003 EOS*
Multi-shock compression is nearly isentropic

This data
Other multi-shock compressed D$_2$ experiments
($T, \rho$ typically inferred from hydro simulations)

![Diagram showing Hugoniot and Isentrope from 10 GPa shock]

- Kerley2003
- Sesame1972
- Ross1998
- Nellis99
- Fortov03
- Ternovoi09
- This data
Conductivity is inferred from optical absorption in shocked D$_2$

Fit using Beer’s Law, $I = I_0 \times 10^{-z/z_0}$, with $z_0 = 15$ μm.

Relate absorption to electrical conductivity using Drude-Zener:

$$\sigma_0 = \frac{\varepsilon_0 c n}{z_0}$$

$\sigma_0 \approx 4$ Ω$^{-1}$ cm$^{-1}$

(D$_2$ conductivity at 10 GPa, 2000 K)
Conductivity is inferred from reflectance of the final shocked state

Measured reflectance (15%) constrains conduction electron density and collisionality within the Drude model:

\[ R = \left| \frac{N - n_1}{N + n_1} \right|^2 \]

\[ N^2 = 1 - \frac{\omega_p^2}{\omega^2} \left( 1 + \frac{i}{\omega \tau_e} \right)^{-1} \]

Drude model electrical conductivity gives*:

\[ \sigma_0 = \frac{n_e e^2 \tau_e}{m_e} \]

\[ \sigma_0 \approx 1050 \ \Omega^{-1} \ cm^{-1} \]

*assuming electron relaxation time \( \tau_e \) time is at Ioffe-Regel limit
Theoretical models of conductivity predict greater density dependence than that observed.
Off-Hugoniot conductivity experiments measure values much lower than those of theoretical models.
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