Opacity measurements at Z

High Energy Density Laboratory Astrophysics
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without Fe

with Fe + Mg

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.
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Z opacity experiments extend measurements beyond $T \sim 150$ eV.

Fe + Mg transmission at $T_e \sim 160$ eV, $n_e \sim 10^{22}$ cm$^{-3}$
Laboratory opacity measurements at stellar interior conditions are not presently available.

<table>
<thead>
<tr>
<th>T(eV)</th>
<th>$n_e$ (cm$^{-3}$)</th>
<th>$\rho$ (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>$1 \times 10^{22}$</td>
<td>0.025</td>
</tr>
<tr>
<td>182</td>
<td>$9 \times 10^{22}$</td>
<td>0.18</td>
</tr>
<tr>
<td>293</td>
<td>$4 \times 10^{23}$</td>
<td>0.77</td>
</tr>
<tr>
<td>1360</td>
<td>$6 \times 10^{25}$</td>
<td>157</td>
</tr>
</tbody>
</table>

Prior data; $T < 50$ eV


This is just one of many situations requiring quality opacity data.
Mid-Z elements pose a challenge for opacity calculations

- Charge state distribution (spectroscopic accuracy)
- What transitions must be included?
- What approximations for configuration and transition grouping?
- What line broadening?
- How accurate are calculations of bound-free absorption?
Anatomy of an opacity experiment

Comparison of unattenuated and attenuated spectra determines transmission

\[ T = \exp \left(-\mu \rho x\right) \]
Desirable features of an opacity experiment

- Sample spatial uniformity (thin, large lateral size, thick tamper)
- Minimal temporal variations during probe time (backlight short compared to heating x-ray variation)
- Steady state (long duration heating x-rays)
- Temperature and density measurements (large wavelength range to enable simultaneous low Z and high Z measurements)

Characteristics of Z x-ray source can promote quality measurements
Opacity experiments can exploit the intense radiation provided by the Z accelerator.
Dynamic hohlraum radiation source is created by accelerating a tungsten plasma onto a low Z foam.
The radiation source heats and backlights the sample.

- X-rays
- Sample
- Radiation source
- Time (nsec): -20 -10 0 10
- Amplitude: 0 100 200 300
- Temperature (eV): 0 100 200 300
- Photon energy ($h\nu > 1$ keV)
- Backlight photons
Two types of opacity measurements have been performed

**Generation I**
Compare shots with and without Fe/Mg

- spectrometer
- CH
- heating
- x-rays

**Fe/Mg sample**

- CH tamper
- backlighter

**Generation II**
Compare spectrometers viewing samples with and without Fe/Mg

- spectrometer 1
- heating
- x-rays

- spectrometer 2

- Fe/Mg sample
Recent experiments used samples characterized with synchrotron x-ray transmission measurements.

- The transmission as a function of photon energy measures areal density of individual sample constituents.
The sample conditions are diagnosed from Mg absorption spectra.
Experiments with and without Fe enable determination of the Fe transmission.

- The difference between Z1363 & Z1364 is the Fe+Mg transmission.
- Assuming shot to shot reproducibility.
The shot to shot reproducibility is good, if conditions are carefully controlled.

- Both experiments used 10 µm CH | 0.3 µm Mg + 0.4 µm Fe | 10 µm CH sample
- No scaling was applied for this comparison
- Reproducibility is approximately 10% or better over this wavelength range
The dynamic hohlraum backlighter measures transmission over a very broad $\lambda$ range.

Z1363-1364
Fe+Mg sample

bound-free

Mg K-shell  Fe L-shell
PRISMSPECT calculations exhibit respectable agreement with Fe transmission

- The main features are well reproduced with > 100,000 transitions
- However, this comparison required adjusting the areal density!
- Comparisons with OPAL are in progress
The data enables tests of the calculated charge state distribution.
goals for future work

- Determine experiment uncertainties
- Evaluate possibility of self emission, non-LTE effects, photopumping, gradients
- Model comparisons
- Optimize tamping and sample design with benchmarked rad-hydro simulations
- Extend to higher densities and temperatures:
  - ZR planned for 2007 completion
  - ZR & use of dedicated experiments should extend measurements to ~ 180-220 eV regime
Z opacity experiments strengthen existing database and extend measurements beyond $T \sim 150$ eV.

Fe + Mg transmission at $T_e \sim 160$ eV, $n_e \sim 10^{22}$ cm$^{-3}$
Transmission for two Fe thicknesses under similar $T_e$ and $n_e$ conditions has been measured.
The transmission data scales with the thickness approximately as expected.

- Significant portions of the spectrum scales with \( T^x \), with \( x = \text{thickness} \)
- This supports method robustness - correct areal density, negligible self emission, correct film response, correct background subtraction
- Residual differences due to line saturation, possibly different Te, ne
The Fe L-shell spectrum exhibits a wealth of line absorption features. Reproducing these features is a difficult test for any opacity model.