Calculations of Ionization Timescales in a Laser-Irradiated Plasma

Valentin Aslanyan (va567@york.ac.uk), 1 Greg Tallents
  1Department of Physics, University of York, Heslington, York, YO10 5DD, UK.

Introduction

- Many models assume Local Thermodynamic Equilibrium (LTE) – ionization levels determined by Saha-Boltzmann equation.
- Collisional-radiative model has been used to determine the time for LTE to be established.
- Relevant to recent studies of EUV laser hole-drilling.

Model

- Zero dimensional plasma.
- Electronic and photonic processes:
  \[ n_e^k = \frac{3 \times 10^{-3}}{t_e} \left( \frac{E_R(T_e)}{E_R(T_i)} \right) \]
  \[ n_e^k = \frac{1}{2} \frac{2 \pi m_e}{h^2} \frac{3}{2} \frac{E_R(T_e)}{E_R(T_i)} \]
- Self consistent electron temperature:
  \[ T_e = \frac{3}{2} \frac{E_R(T_e)}{E_R(T_i)} \]
- Continuum lowering (Stewart-Pyatt):
  \[ \Delta E = \frac{1}{2} \frac{2 \pi m_e}{h^2} \left( \frac{E_R(T_e)}{E_R(T_i)} \right) \]
- Ions and electrons have velocity distributions (verified by Spitzer formula):
  \[ f(v) = f_{Maxwell}(T_e) \]
- Time dependence solved by regular RK-4 algorithm.

Hydrogen: Analytical Comparison

- Possible to derive an analytic expression to confirm the algorithm:

Carbon: Ionization from Solid

- Incident radiation photoionizes electrons and injects energy into the system.
- Electron temperature drops initially and begins to recover as Inverse Bremsstrahlung absorption increases.

Energy Deposition Scenarios

- Simulation of system where energy is injected to raise electron temperature from cold (25eV) to hot (100-1000eV).
- Energy is raised by linear coupling to electrons or via photoabsorption.

Density-dependent Timescales

- Electron-ion
- Electron-electron

Conclusions

- The assumption of LTE is valid for many hydrodynamic processes.
- Processes on timescales longer than of order femtoseconds do not require a full rate treatment to accurately model population levels.
- Equilibration times have a quadratic dependence on ion density.

Future Work

- The effects of a super-Gaussian electron distribution on equilibrium populations in the presence of non-thermal radiation is relevant to current ICF experiments.
- Scenarios with different incident radiation are being explored.

References