Hierarchy of Stopping Powers

Matthew Terry, Gregory Moses

Fusion Technology Institute, University of Wisconsin-Madison

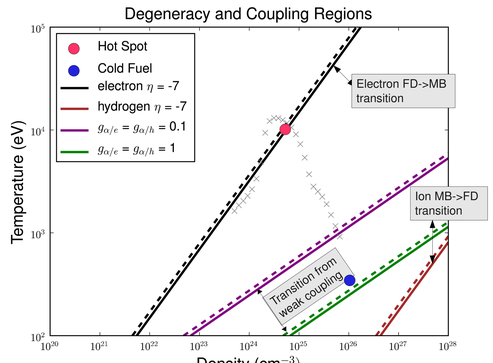
April 29-31, 2009 Omega Users Group Workshop, Rochester, NY

Abstract

Accurate treatment of fusion charged particle transport is important for understanding ICF ignition implosions as well as charged particle diagnostics. Over the years, many models have been proposed, each assuming different plasma regimes and having different validity constraints. Here we present a comparison of the most popular models and present a detailed analysis of their validity constraints. We present a comparison of the models of Landau/Trubnikov/Rosenbluth; Li and Petrasso; Brysk; Skupsky; Brown, Preston, and Singleton; and a Fermi-degenerate generalization of Li and Petrasso's model. We propose methods of experimentally distinguishing stopping power models.

Work supported by Sandia National Laboratory through NPSC Fellowship

Validity regions for weak coupling and Maxwellian distribution functions

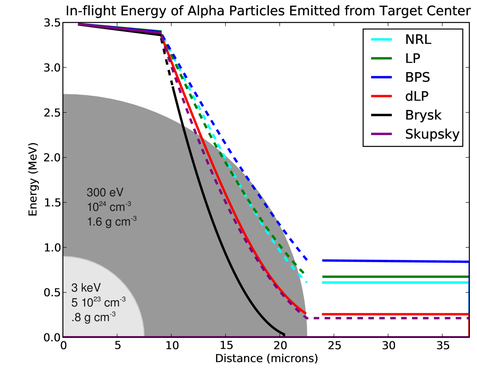


X's are temperature-density profile points from an ignition simulation

Mutually valid models give inconsistent predictions

- **Even under mutually "valid" conditions, stopping power models do not agree**
- **Both collisional and dielectric effect important**
- **Ambiguity in Coulomb logarithm responsible for most of the variation**
- **Convergent models seem to include collisional and dielectric effects correctly, but are currently restricted to Maxwellian plasmas**

Stopping powers may be experimentally differentiable via energy shift



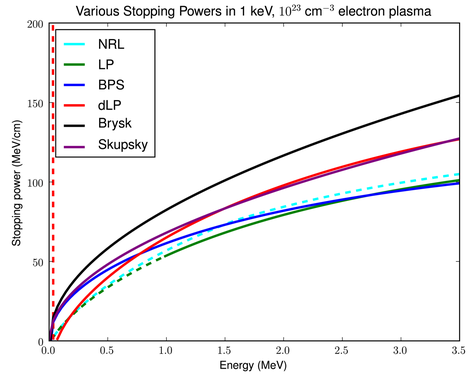
Summary

- **Stopping power models have (sometime strict) theoretical limitations**
- **Different models model different physics, which have their own restrictions**
- **Mutually valid models give inconsistent answers**
- **Developed stopping power library (deeks) that implements many models with validity checking**
- **Deeks can be used to help design experiments that will validate theory**
- **Deeks can be used to aid interpreting detector data and used to infer experimental quantities**

Mathematical simplifications restrict validity

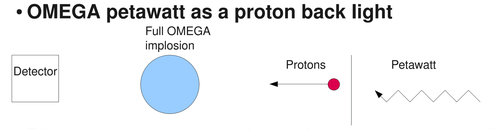
- **Dielectric models expect (incident ion v) < (electron thermal v)**
- **Boltzmann models expect a large Coulomb logarithm**
- **Neither happen consistently in ICF plasmas**
- **Convergent models are currently restricted to Maxwellian distribution functions**

Mutually valid models can differ up to a factor of 2

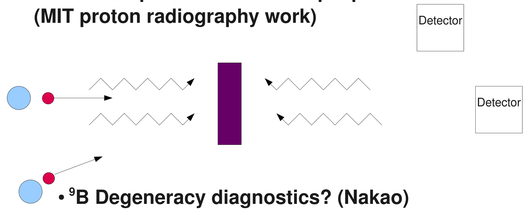


Stopping power measurement brainstorming

- **OMEGA petawatt as a proton back light**



- **Planar compression with multiple proton sources? (MIT proton radiography work)**

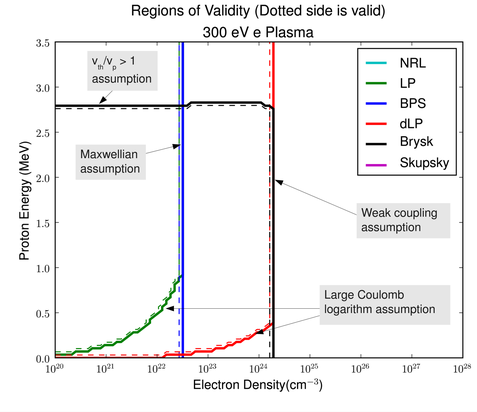


- **^{9}B Degeneracy diagnostics? (Nakao)**

Plasma Properties Limit Scope of Theory

- **Statistical descriptions of a plasma depend on the plasma parameter (aka coupling parameter aka inverse particles in a Debye sphere) being small, the "weak coupling approximation"**
- **We should be aware of when a plasma is no longer weakly coupled**
- **Stopping power models make assumptions regarding the plasma's distribution function (usually that it is Maxwellian)**
- **We should be aware of when a plasma is no longer Maxwellian, and use an appropriate (semi) Fermi degenerate model**

Validity map has complicated structure



Experiments are needed to validate convergent model

- **Previous models have taught caution in applicability of models**
- **Additional work needed to get degenerate BPS-like model**
- **Unanswered questions:**
  - **Is atomic structure significant?**
  - **Effect of magnetic field perturbations?**
- **Ultimately need to experimentally measure the stopping power**

Conclusion

- **Charged particle transport is not a solved problem**
- **Many (sometimes contradictory) models exist for different transport regimes**
- **Implemented a library (deeks) that contains all major models with significant validity checking**
- **Useful for designing experiments to measure/differentiate between models**