ELM Suppression and Pedestal Structure in I-Mode Plasmas on Alcator C-Mod

by

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S.B. Physics & Mathematics (2010)
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Submitted to the Department of Nuclear Science and Engineering
in partial fulfillment of the requirements for the degree of

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Abstract

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A dedication goes here maybe?

ACKNOWLEDGMENTS

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INTRODUCTION

some sort of motivation goes here

1.1 PLASMAS FOR FUSION

A *plasma* is a gas to which sufficient energy has been applied to strip some or all of the electrons off the nuclei of its constituent atoms. These ions and electrons freely interact with one another, behaving as coupled fluids. Plasmas of interest for fusion research are comprised of light elements (typically Hydrogen or Helium), and are at extremely high temperatures, in excess of 100 million Kelvin ($10-20$ keV). As these conditions are far in excess of the ionization energy for these elements, the plasma is dominated by collisions between its charged particles, rather than interactions with bound electron states.

1.1.1 *Plasma Parameters*

As the plasma is comprised of free charged particles, it responds strongly to electric and magnetic fields. In the presence of a DC electric field (externally applied, or generated by an imbalance of positive and negative charge in the plasma), the plasma will rearrange itself to screen out the field. This effect breaks down at short length scales, at which there is an insufficient number of charge carriers to rearrange and counter the field – the characteristic scale for this effect is the Debye Length, given by

$$\lambda_D = \sqrt{\frac{\varepsilon_0 T}{n e^2}} \tag{1.1}$$

At size scales significantly larger than λ_D, this will enforce an approximately balanced electric charge in the plasma, termed "quasineutrality". This is reflected in the number densities of electrons and multiple ion species j, each with charge Z_j, by the relation

$$n_e = \sum_j n_j Z_j \tag{1.2}$$

In a multiple-ion species plasma, we may also define an effective ion charge

$$Z_{eff} = \sum_j n_j Z_j^2 \tag{1.3}$$

The electrostatic force driving this charge redistribution induces a "ringing" oscillation in the plasma, at the characteristic plasma frequency ω_p:

$$\omega_p = \sqrt{\frac{ne^2}{\varepsilon_0 m_e}} \tag{1.4}$$

This natural oscillation in the plasma also has the effect of screening AC electric fields varying at frequencies $\omega < \omega_p$.

Coulomb collisions between charged particles in the plasma tend to drive magnetically-confined plasmas into thermal equilibrium, with the velocity distribution for a species given by the Maxwellian

$$f(\nu) = n\left(\frac{m}{2\pi T}\right)^{3/2} \exp\left(-\frac{m\nu^2}{2T}\right) \tag{1.5}$$

These collisions also cause the plasma to emit a continuous spectrum of Bremsstrahlung radiation. For a plasma in thermal equilibrium, integration over the full spectrum gives for the total radiated power

$$P_{Brems} = \left(5.35 \times 10^{-37}\right) n_e^2 Z_{eff} \sqrt{T} \tag{1.6}$$

1.1.2 *Fusion Fuels*

Fusion collectively refers to the class of nuclear reactions merging lighter nuclei into a single heavier element. While fusion reactions for elements lighter than iron are generally exothermic, the most common and readily attainable involve isotopes of hydrogen or helium, the most promising candidates for which are shown below.

$$^2\mathrm{D} + {}^2\mathrm{D} \rightarrow {}^3\mathrm{T} + \mathrm{p} + 4.03\ \mathrm{MeV} \tag{1.7}$$
$$^2\mathrm{D} + {}^2\mathrm{D} \rightarrow {}^3\mathrm{He} + \mathrm{n} + 3.27\ \mathrm{MeV} \tag{1.8}$$
$$^2\mathrm{D} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + \mathrm{p} + 18.3\ \mathrm{MeV} \tag{1.9}$$
$$^2\mathrm{D} + {}^3\mathrm{T} \rightarrow {}^4\mathrm{He} + \mathrm{n} + 17.6\ \mathrm{MeV} \tag{1.10}$$

Here D and T indicate nuclei of deuterium and tritium, two heavy isotopes of hydrogen (one proton plus one and two neutrons, respectively).

Figure 1.1: Binding energy per nucleon versus atomic mass number, with notable isotopes marked.

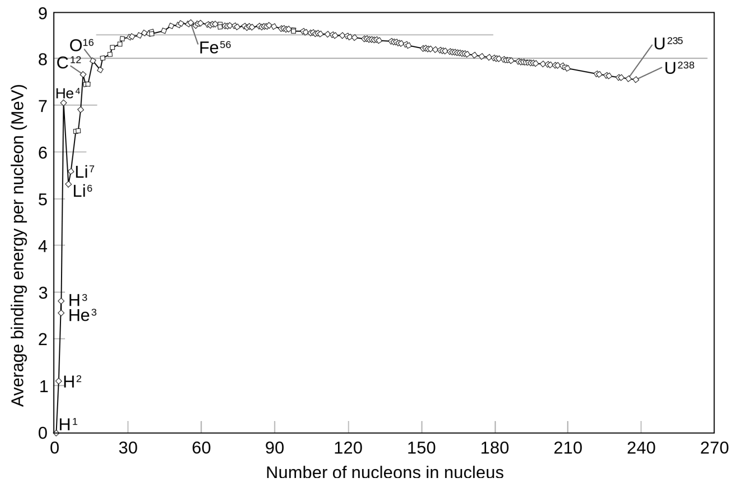
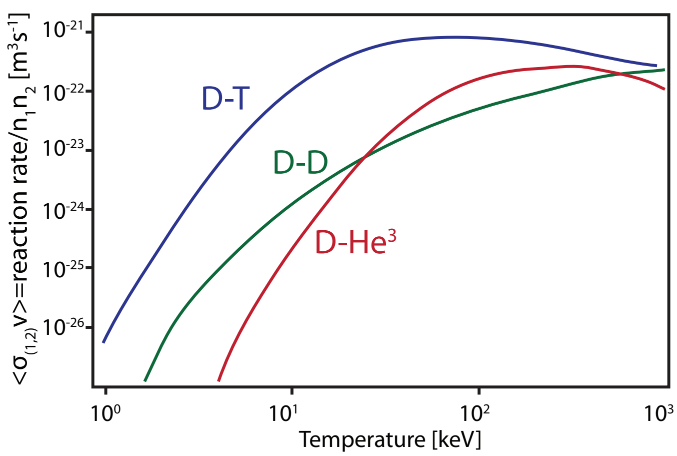


Figure 1.2: Reaction rate coefficients for fusion fuels.



Pure deuterium fuel (reactions shown in eqns. 1.7 and 1.8) is attractive from a research standpoint, due to the abundance and ease of use of deuterium. Deuterium is a stable nucleus, obviating the need for radiation safety on the fuel system, and is naturally occurring in relative abundance (approximately 1/6000 of hydrogen nuclei on earth are deuterium cite), allowing harvesting of deuterium fuel from seawater. However, pure-deuterium reactions suffer from low energy output per reaction (see Figure 1.2) and a significantly lower reaction rate at feasible plasma conditions compared to other fuel options, setting high performance requirements for a putative DD-burning reactor.

1.2 MAGNETIC CONFINEMENT

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1.5.1 *ELMy H-Mode*

1.5.2 *EDA H-Mode*

1.5.3 *I-Mode*

1.6 GOALS & OUTLINE

COLOPHON

This document was typeset using `classicthesis` developed by André Miede (although aspects were changed to comply with the MIT thesis standards and the author's personal preferences). The style was inspired by Robert Bringhurst's seminal book on typography "*The Elements of Typographic Style*". `classicthesis` is available for both LaTeX and LyX:

`http://code.google.com/p/classicthesis/`

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