§43. Degeneracy Diagnostics of Imploded DT Plasmas Based on Nuclear Reaction Products Measurement

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1. Purpose and Diagnostics Senario

In superdense plasmas as realized by laser implosion, the electrons should be in Fermi degenerate state. One of the consequences of electron degeneracy is reduction in the stopping power of the plasma for energetic charged particles. Accordingly, their ranges (in g/cm^2 unit) are lengthened than in the case of non-degenerate electron plasma. The electron degeneracy might have influences on the ignition condition in the fast ignition scheme where the implosion is tailored so as to keep the isentrope parameter α close to 1. How to diagnose the degree of electron degeneracy in compressed DT fuel for fast ignition is hence a matter of interest.

The purpose of this study is to propose a new method to diagnose the degree of electron degeneracy in compressed fuel for fast ignition. To this end we considered a DT fuel admixed with a small amount of ^{9}Be and examined the possibility of degeneracy diagnostics using the following alpha-particle-induced reaction [1] :

$$\alpha + {}^9\mathrm{Be} \rightarrow {}^{12}\mathrm{C}^*[2^+;0] + n\,;$$
$$ {}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C}\,[\mathrm{gr.}] + \gamma \;\; (E_\gamma = 4.44\mathrm{MeV}).$$

In our scenario it is supposed that the fuel pellet is compressed to high densities by implosion such as tailored for fast ignition, but is not subjected to any heating laser. In such a case, the fuel would not be ignited, and most of the nuclear reactions would occur around the maximum compression. Thus, nuclear reaction products are expected to carry information about the compressed state of the fuel such as the degeneracy Θ. This parameter is defined by $\Theta \equiv kT_e\,/\,E_F$, where T_e is the electron temperature, and E_F is the Fermi energy, *i.e.*

$$E_F = (\hbar^2/2m_e) \times (3\pi^2 n_e)^{2/3}. \qquad (1)$$

In Ref. 1, an infinite plasma was assumed. In this stdy, we made calculations for finite-sized fuel pellets.

2. Reaction Probability

First, assuming DT/^{9}Be pellets compressed to various areal densities, we calculated the probability $P_{\alpha\text{-}Be}$ that the $\alpha + {}^9$Be reaction occurs during the slowing down and transport of α-particle as a function of the degeneracy parameter Θ and the plasma temperature. **Figure 1** shows the calculated reaction probability $P_{\alpha\text{-}Be.}$ In the calculation the fractional number density of ^{9}Be admixture was fixed to $n_{Be}/n_i = 0.1$. The dotted lines show the result for an 'infinite' plasma. We can see that the probability $P_{\alpha\text{-}Be}$ has clear dependences on the degeneracy parameter Θ and the plasma temperature. For fixed temperature, $P_{\alpha\text{-}Be}$ increases with decreasing Θ. This is because reduction in the mass stopping power due to the electron degeneracy is more pronounced for smaller Θ.

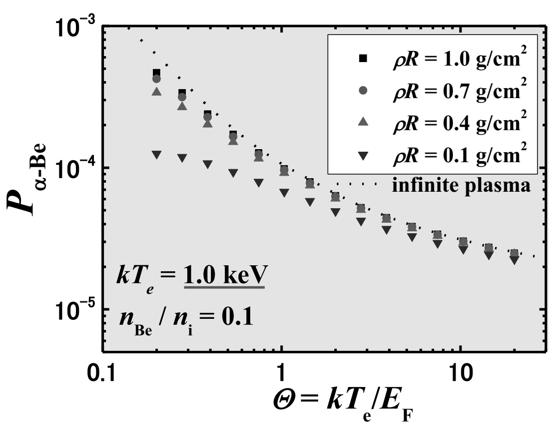

Fig. 1 Reaction probability vs. degeneracy parameter

Experimentally, the reaction probability $P_{\alpha\text{-}Be}$ would be determined as the ratio of the 4.44- MeV γ- ray yield to the DT neutron yield. Thus, if the plasma temperatures T_e and T_i are determined in other ways (*e.g.* Doppler broadening of neutron spectrum, X-ray spectrometry), we can assess the degeneracy parameter Θ from the diagnostic $P_{\alpha\text{-}Be}$-Θ curve by measuring the 4.44-MeV γ-rays and DT neutrons.

3. γ-Ray Yield from Compressed Pellets

Next, we estimated the yield of 4.44-MeV γ-rays emitted from the compressed finite-sized DT/^{9}Be pellets. If we ignore the spatial distributions of plasma temperature and density, their temporal evolutions, and the leak of α-particles, the yield per shot may be roughly estimated by

$$N_{\gamma,\,4.44\,\mathrm{MeV}} = P_{\alpha\text{-}Be} \times S_\alpha \times V \times \tau, \qquad (2)$$

where S_α is the instantaneous rate of the α-particle generation per unit volume, V is the plasma volume, and τ is the time interval while the high density state is maintained and most of the electron components are expected to be in degenerate state. A simple estimate of τ is given by $\tau = R/3c_s$, where R is the plasma radius and c_s is the sound velocity in the plasma. In the cases that $\rho R = 0.4$ g/cm^2, ρ = 200g/cm^3, $n_{Be} = 0.1\, n_i$ and kT_e = 0.4～1.0keV, for example, the yield was estimated to be 10^5 ～10^7. The yields estimated seem enough for the γ-rays to be detected.

4. Remarks for Future Work

In the above calculations we assumed homogeneously -compressed DT/^{9}Be pellets. The actual pellet configuration, however, is not homogeneous. Moreover, the temporal evolutions of density-temperature profiles, γ-ray and DT neutron generation rates are also important. Thus, for further examination of diagnostics scenario, analysis including implosion dynamics is indispensable.

1. Y. Nakao, et al., Fusion Sci. Technol., **56**, 391, 2009.