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Effect of nuclear elastic scattering on behavior of fast α-particles in tokamak plasmas

トカマクプラズマ中の高速α粒子挙動における核弾性散乱の影響

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Assuming ITER-like plasma, the nuclear plus interference (NI) scattering is newly incorporated into the alpha-particle orbit simulation code system. The NI scattering effect on the alpha-particle orbit in the magnetic confinement device and the influences on the energetic alpha-particle confinement are examined. It is shown that due to the NI scattering, a fraction of the energetic alpha-particle lost from the plasma to total generation decreases to some extent.

1. Introduction

To realize the fusion reactor system, it is important to understand the fast alpha-particle confinement and slowing-down process in magnetic field configuration, and hence many numerical simulations have been made in various reactor systems [1-3]. In the previous alpha-particle orbit analyses, however, the effect of nuclear plus interference (NI) scattering [4] on the alpha-particle behaviors has not been considered. The NI scattering is a non-Coulombic, large-angle scattering process, and a large fraction of the fast-ion energy is transferred in a single event. The NI scattering may influence behavior of fast ions. The purpose of this study is to reveal the effect of NI scattering for confinement of alpha-particle and plasma heating process.

2. Analysis Model

We incorporated the NI scattering effect into the orbit analysis code, i.e. guiding center orbit code ORBIT [5] developed at PPPL.

The probability *p(v)* that a test particle moving with velocity v causes NI scattering during small time step Δt is

$$p(v) = n_b v \sigma_{NI} \Delta t \quad , \qquad (1)$$

where n_b is number density of background ions, and σ_{NI} is cross section of NI scattering. As a first step, the effect of thermal motion of target particles, i.e. deuteron and triton, was neglected. This is because the cross section of the NI scattering is very small in low energy region (<1MeV). Scattering angle in the center of mass system ϕ was assumed to be isotropic. Transferred energy in a single scattering event ΔE can be written as

$$\Delta E = \frac{E}{2}(1-\alpha)(1-\cos\phi) \quad , \qquad (2)$$

where E is kinetic energy of the test particle before scattering. Here $\alpha=\{(m_t-m_b)/(m_t+m_b)\}^2$, m_t and m_b are mass of test particle and background ion. In this paper, the NI scattering cross sections are taken from the work of Perkins and Cullen[6].

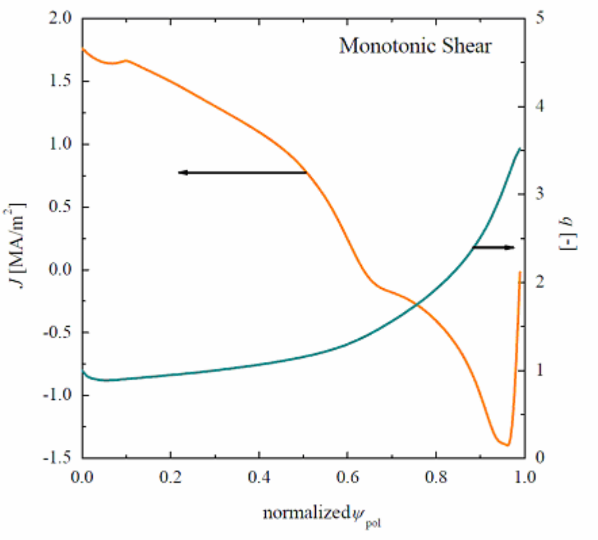

Fig.1. Safety factor and current distribution assumed this calculation [7]

We assumed ITER-like plasma. Toroidal magnetic field B_T=5.3T, and radial profiles of bulk ions and electrons densities $n_i=n_e=1.0\times10^{14}\times(1-\psi_{pol,n}^2)^{1.5}$ are assumed, where $\psi_{pol,n}$ represents the normalized poloidal magnetic flux function ψ_{pol}.

Radial profiles of the safety factor and current density are shown in Fig.1 [7]. Throughout the calculations, 30000 test particles and 100000 toroidal period calculation time are assumed.

3. Result and Discussion

In Fig.2, (a) fraction of the number of test particles that causes NI scattering to the ones initially generated, i.e., N_{NI}, and (b) fraction of energy deposited to bulk ions via NI scattering to the ones initially generated, i.e., f_{NI}, are shown as a function of electron temperature.

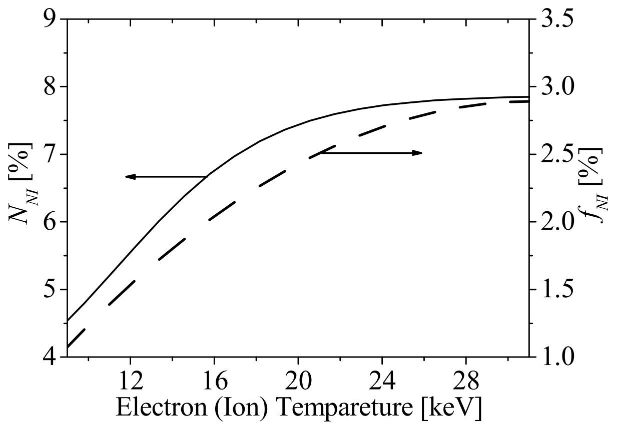

Fig.2 The n_{NI} parameter and the f_{NI} parameter as functions of average temperature of ions

The fraction of the number of test particles that causes NI scattering, i.e., N_{NI}, is increased in high temperature range. This is because in high temperature range, slowing down of energetic alpha-particles by Coulomb scattering is weakened and relative magnitude of the energetic alpha-particle distribution function to bulk component is increased. The fraction of the deposited energy via NI scattering, i.e., f_{NI}, is similarly increased in high temperature range.

When electron temperature is 20 keV, fraction of the energy deposited to ions via NI scattering is 2.45 % and the fraction of the energy deposited to ions (electrons) via Coulomb scattering is estimated as 28.9 (68.5) %. In this case the enhancement of the fractional energy deposition to ions due to NI scattering is evaluated as 5.8 %.

In Fig.3, (a) fraction of the energy lost from the plasma to the one initially generated, i.e., ξ, and (b) the degree of the decrement from the value when NI scattering is ignored, i.e., $\eta=(\xi_0-\xi)/\xi_0$, are shown. Here ξ_0 represents the ξ value when the NI scattering is ignored. As previously mentioned, relative magnitude of the energetic alpha-particle component is relatively increased in high temperature range. The energetic alpha-particles are more difficult to trap in the magnetic field compared with the low energy ones. Thus the ξ value increases in high temperature range. When NI scattering is ignored, slowing down of energetic alpha-particles is underestimated compared with the case when NI scattering is considered, and relative magnitude of the energetic alpha-particles to the bulk component is further decreased. When NI scattering is ignored, hence the ξ value tends to have large values over all the temperature range compared with when NI scattering is considered. For example at 20keV temperature, it is shown that lost energy is decreased by about 6.5% due to NI scattering.

It is well known that as a result of NI scattering the energetic alpha-particle changes its moving direction significantly. In the subsequent study, the effect on the alpha-particle confinement should also be evaluated.

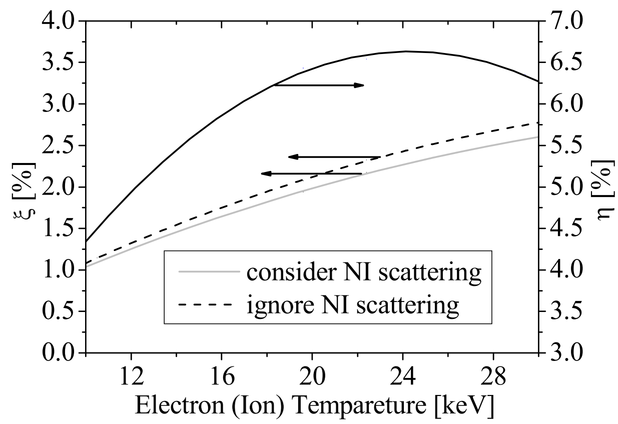

Fig.3 Temperature dependence of rate of energy loss and decreasing rate of energy loss by NI scattering

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