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Effect of nuclear plus interference scattering on α-particle orbit and slowing-down distribution function in magnetic field configuration
磁場中のα粒子軌道と減速分布関数に対する核弾性散乱の影響

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Assuming a deuterium-tritium (DT) burning plasma, effect of the nuclear plus interference (NI) scattering is newly incorporated into the alpha-particle orbit simulation. The effect of the NI scattering on 2D energetic alpha-particles velocity distribution function and confinement in a magnetic fusion device is examined. It is shown that due to alpha particle slowing-down and transition of pitch angle by NI scattering, the fraction of the alpha-particles lost from the plasma during their slowing-down process to the initial generation decreases to a certain extent.

1. Introduction

In magnetic confined fusion plasma, it is important to understand the fast-ion behavior from the viewpoint of plasma heating and heat load on the first wall. Particle orbit analysis is useful to understand the fast-ion behavior in thermonuclear plasmas, and has been used to examine, for example, the diffusion of fast ions in a magnetic field [1]. It is well known that for fast-ions, Coulomb and non-Coulombic, i.e. nuclear plus interference (NI) [2], scattering (The NI scattering is defined by subtracting Coulomb contributions from experimental data. It is also referred to as "nuclear elastic scattering (NES)") contribute to the fast-ion slowing down process. NI scattering is caused by nuclear force plus nuclear Coulomb interference when ions are close enough. The Coulomb scattering process is characterized by many small-energy-transfer events. The NI scattering is a large-angle scattering process, and a large fraction of the fast-ion energy is transferred in a single event. So far in the previous particle orbit analyses, the effect of the NI scattering has not been considered.

NI scattering changes direction of the particles motion and the number of particles scattered into the loss cone. Assuming the magnetic mirror device, Kantrowitz and Conn noted that particle loss is increased by NI scattering [3]. On the other hand, NI scattering accelerate the fast-ion slowing-down. If we neglect the NI scattering effect, slowing-down time of the fast-ion is overestimated [4]. The influence on the fast-ion distribution function, i.e. decrement in energetic component in the slowing-down distribution function, has been evaluated [5,6]. However, these analyses were made on the basis of the Boltzmann- Fokker-Planck (BFP) simulation, i.e., particle orbit in the magnetic field configuration was not considered. When NI scattering accelerate the fast-ion slowing-down, its loss rate could be decreased. In the magnetic field, it is also well known that collisions change the particle orbit pattern and affect the particles confinement properties [7]. The NI scattering could also be influential on the particle orbit and the confinement properties. Fast ions lost from an articular orbit may be concentrated on a spot on the first wall. It is important to grasp the NI-scattering effect on the fast-ion loss process in fusion devices. In previous study, we mainly consider transition of the alpha-particle orbit by NI scattering [8]. However, alpha-particles velocity distribution function is not discussed. If energetic alpha-particle slowing-down and orbit is changed by NI scattering, 2D alpha-particles distribution function is also changed.

The purpose of this study is to reveal the mechanism of energetic alpha-particles loss process in based of 2D distribution function.

2. Analysis Model

The NI-scattering effect was incorporated into the charged-particle orbit analysis code, i.e. guiding center orbit code ORBIT [9] developed at PPPL.

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

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

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[10].

We assumed ITER-like plasma. Toroidal magnetic field B_T=5.3T, and radial profiles of bulk ions and electrons densities $n_i=n_e=1.0\times10^{14}\times(1-\psi_{pol,n}{}^2)^{1.5}$ cm^{-3} are assumed, where $\psi_{pol,n}$ represents the normalized poloidal magnetic flux function ψ_{pol}. Throughout the calculations, 200000 test particles and 100000 toroidal period calculation time are assumed.

3. Result and Discussion

Fig.1 shows 2D velocity distribution function of alpha-particles in ψ > 0.5 region after 100000 toroidal transit time when NI scattering is considered. Where v_α represents velocity of 3.52MeV alpha-particles, $v_{//}$ and $v_\perp$ are parallel and vertical components of the particle velocity to the magnetic field. Lost alpha-particles 99% exist in this ψ > 0.5 region before loss. We can see 2D distribution function has anisotropy by particle orbit and low velocity alpha-particles exist via NI scattering.

Alpha-particle orbit can be divided into two patterns, i.e. trapped and untrapped orbit. Alpha-particles moving on the trapped orbit satisfy the following requirement [7]

$$\frac{v_{//0}}{v_{\perp 0}} = \frac{1}{|\tan\theta_0|} < \left(2\frac{r_0}{R_m}\right)^{1/2} , \qquad (3)$$

Where θ and r are pitch angle and the distance from the plasma center, subscript 0 means when the particle passes a point Z=0. From inequality (3), alpha-particles in outer region have small $v_{//}$ and large $v_\perp$.

We consider trapped particles because most of the alpha-particles are lost from the trapped orbit. In Fig2, pitch angle distribution of trapped alpha particles is plotted. In 100° < θ < 110° region, alpha particle distribution is 4% decreased when NI scattering is considered. Decrease of trapped alpha particles reduces alpha particle loss.

At the presentation, we discuss process of decrease of alpha-particles pitch angle distribution and loss.

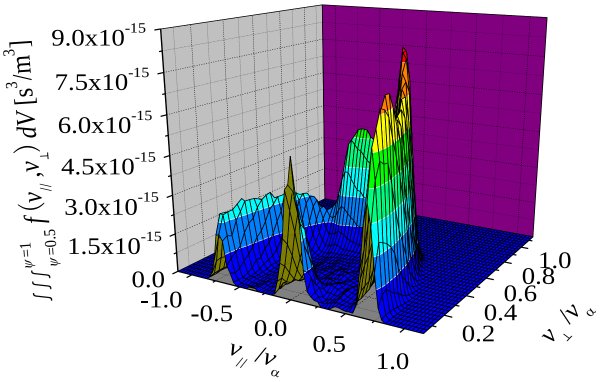

Fig.1. 2D alpha-particles distribution function in region ψ>0.5 when NI scattering is considered

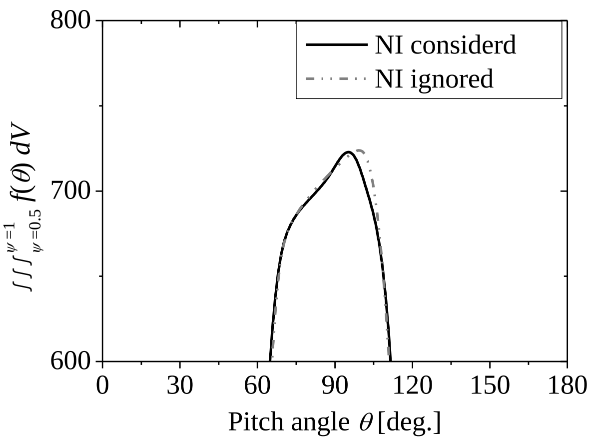

Fig.2 Pitch angle distribution of trapped alpha-particles in region ψ>0.5

References

[1] A. H. Boozer and G. Kuo-Petravic: Phys. Fluids, **24** (1981) 851.

[2] J. J. Devaney and M. L. Stein, Nucl: Sci. Eng., **46** (1971) 323.

[3] F. D. Kantrowitz and R. W. Conn: Nucl. Fusion, **24** (1984) 1335.

[4] Y. Nakao, et al.: Nucl. Fusion, **28** (1988) 1029.

[5] H. Matsuura, et al.: Phys. Plasmas, **13** (2006) 62507.

[6] H. Matsuura, et al.: Plasma Fusion Res., **7** (2012) 2403076.

[7] B. B. Kadomtsev and O. P. Pogutse: Nucl. Fusion, **11** (1971) 67.

[8] D. Sawada, et al.: Plasma Fusion Res., **8** (2013) 2403033.

[9] R. B. White, et al.: Phys. Fluids, **27** (1984) 2455.

[10] S. T. Perkins and D. E. Cullen: Nucl. Sci. Eng., **77** (1981) 20.