8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Alpha particle distribution in the full velocity space

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The physics of alpha particles is a critical issue in burning D-T plasmas. An accurate knowledge of alpha particle distribution is crucial to study the interaction between alpha particles and background turbulence and transport. The conventional slowing down distribution derived by Gaffey[1] is widely used as the equilibrium distribution of alpha particles. However, this distribution is not applicable to the low velocity region due to the omission of the energy diffusion term in the collision operator during its derivation. Moreover, the turbulence can also result in correction to the conventional slowing down distribution. Thus, the alpha particle distribution in the full velocity space still need further research.

In this work, the alpha particle distribution is studied in the full velocity space. The Fokker-Planck equation near the equilibrium state is analytically solved using an iteration method for alpha particles. The resulting distribution includes a Maxwellian part, a modified slowing down part, and a high energy tail part.[2] It aligns with the conventional slowing down distribution in the high velocity region $v_a > 3v_{thi}$, and the Maxwellian distribution in the low velocity region $v_a < 1.5v_{thi}$, where v_α is the alpha particle velocity and v_{thi} the thermal velocity of background ions. In the velocity range $1.5v_{thi} < v_\alpha < 3v_{thi}$, the distribution is described by the sum of the Maxwellian part and modified slowing down part. The influence of micro-turbulence on the alpha particle distribution is considered as well through modeling its induced transport as a local sink term in the Fokker-Planck equation. It is shown that the modified slowing down part in the relatively high velocity region undergoes little correction while the amplitude of the Maxwellian part is sensitively influenced by the resonant velocity of turbulence. Under appropriate parameters, the bump-on-tail distribution is observed.

In both cases with and without transport effects, the Fokker-Planck equation is numerically solved. It is shown that the full temporal evolution of the system can be divided into three stages: the slowing down stage, thermalization stage, and quasi-steady state stage.[2] In the slowing down stage, alpha particles are generated and gradually transfer energy to the background particles. After a time period of about the slowing down time τ_S, the slowing down part is established. Since no alpha particles enter the low velocity region, the Maxwellian part remains unformed. In the thermalization stage, alpha particles start to enter the low velocity region $v_a < 1.5v_{thi}$, leading to the establishment of the Maxwellian part. The characteristic timescale of this stage is very short compared to τ_S. In the quasi-steady state stage, the modified slowing down part becomes steady and almost does not change over time. The number of alpha particles generated from the source is approximately equal to the increase in the number of particles of the Maxwellian part. The numerically obtained alpha particle distribution in this stage agrees well with the theoretical results.

It is believed that the above findings will promote the understanding of alpha particle distribution in the full velocity space and its temporal evolution, and be of great significance for the study of heating and instabilities in burning plasmas.

This work was supported by the National MCF Energy R&D Program under grant no. 2018YFE0311300.

References

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