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Comparison of Collisional and Turbulent Energy Exchanges between Ions and Electrons in Tokamak Plasmas

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In magnetically confined plasmas, turbulence induces particle and heat fluxes, and also causes energy exchange between electrons and ions [1, 2]. In a previous study [3], the effect of turbulent energy exchange on prediction of plasma density and temperature profiles was investigated under specific conditions and it was found to be negligible. However, the paper [3] did not make a detailed comparison between the turbulent and collisional energy exchanges in the case of very high-temperature plasmas such as those in ITER, where the collision frequency is very low.

In this work, effects of ion temperature gradient (ITG) turbulence on the energy exchange between electrons and ions in tokamak plasmas are quantitatively investigated by gyrokinetic simulations and their dependence on plasma conditions such as collision frequency and the electron-to-ion temperature ratio is clarified. In addition, the ratio of turbulent and collisional energy exchanges is evaluated, and a wavenumber space spectral analysis is performed to elucidate the mechanism of the turbulent energy exchange.

We use the gyrokinetic simulation code GKV[4] and focus on the ITG turbulence under the Cyclone DIII-D Base Case plasma conditions [5]. Here, kinetic electrons are considered, and the electron temperature gradient is assumed to be zero. The ion beta $\beta_i = 1 \times 10^{-4}$ is used and the ratio of the electron and ion temperature is varied from $T_e/T_i = 0.8$ to 1.5.

There are different properties between collisional and turbulent energy exchanges. As the plasma temperature is increased, the collisional energy exchange decreases and the turbulent energy exchange increases. Therefore, turbulent effects dominate the energy exchange at high temperature (low collision frequencies). Also, the direction of energy exchange is clearly different when $T_e/T_i > 1$. Figure 1 shows the turbulent and collisional energy exchange as functions of the temperature ratio T_e/T_i. Here, Q_i^{coll} and Q_i^{turb} are defined as the collisional and turbulent energy transfers from electrons to ions, respectively. Coulomb collisions make energy transfer from hotter to colder species. However, in the ITG turbulence, energy can flow from colder ions to hotter electrons. Figure 1 shows that, even for $T_e > T_i$, the net energy can flow from low temperature ions to high temperature electrons. Furthermore, in isothermal plasma conditions, the collisional energy exchange vanishes while the turbulent one doesn't.

In addition, we investigate the physical mechanism of turbulent energy exchange in ITG turbulence and the correlation between the results of linear and nonlinear calculations.

References

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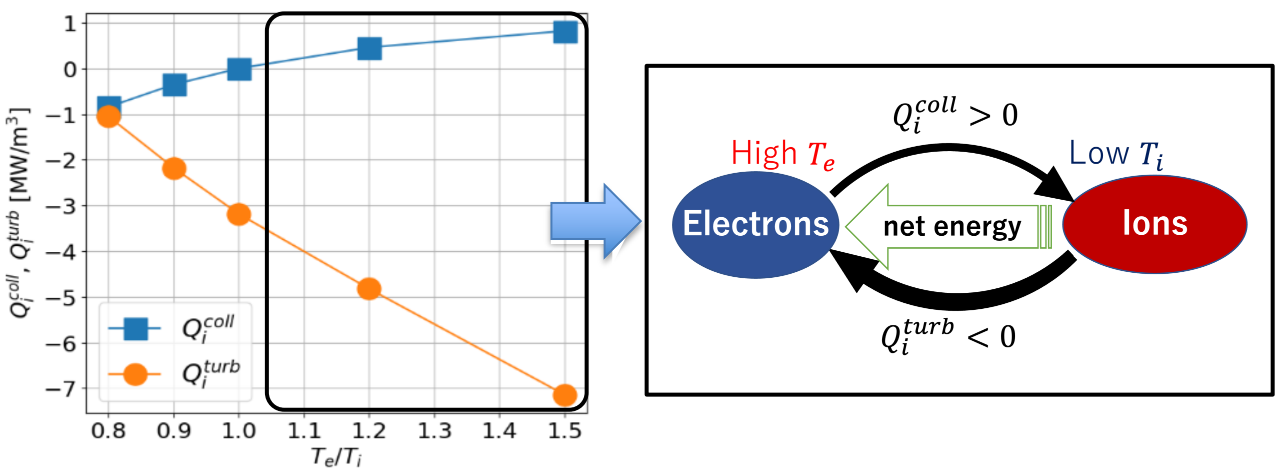

Figure 1. The collisional and turbulent energy transfers, Q_i^{coll} and Q_i^{turb}, from electrons to ions are plotted as functions of the electron-to-ion temperature ratio T_e/T_i ($T_i = 3.0$ keV, $n_e = n_i = 1 \times 10^{20}$ m^{-3}, $B = 2.2$ T). When $T_e/T_i > 1$, turbulent energy exchange exhibits a larger magnitude and an opposite direction compared to collisional energy exchange.