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Quasi-linear heat transport induced by ITG turbulence in the presence of impurities

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Understanding anomalous mechanisms of heat transport in tokamak plasmas with multiple ion species, through the ion and electron channels, is a key element in achievement of burning plasmas. Great efforts and significant progress on the particle transport induced by micro-instability have been developed theoretically[1-3] and experimentally[4,5]. However, the underlying physics mechanisms of heat transport are far from a systematic investigation, in particular taking the impurity ion effects into account.

The impurity effects on turbulent transport induced by ion temperature gradient (ITG) turbulence are numerically studied, using a gyrokinetic quasi-linear model. The characteristics of the instability and heat fluxes in the presence of impurity ions are investigated for a broad parameter regime, including temperature and density gradients of main and impurity ions, concentration, charge and mass numbers of impurity ions, magnetic shear as well as wave vector spectrum. The heat fluxes are demonstrated to depend not only on the saturation amplitude of the instability but also on the phase shift between perturbed temperature $\tilde{T}_s$ and velocity $\tilde{v}_{E\times B}$. The peaking factor of temperature/ density profile, defined as the ratio of major radius to gradient scale length ($PF_{ns} = -R\nabla n_s/n_s = R/L_{ns}$) when the total turbulent heat flux equals zero, is fitted with linear/quadratic functions, as shown in figure 1.

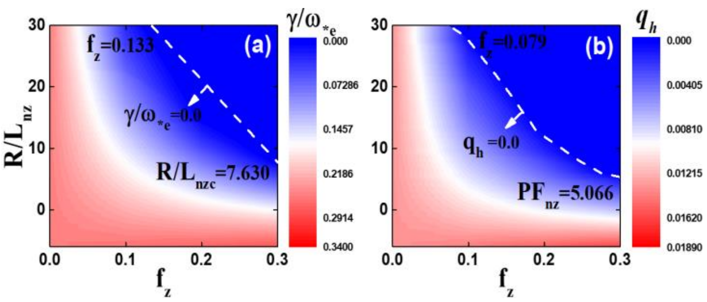

Figure 1. Contour plots of the growth rates γ/ω_{*e} and heat fluxes q_h in the presence of impurity ions.

Figure 2 represents summed heat flux of main and impurity ions and its components versus ion temperature gradient R/L_{Ti}. The contributions from diagonal and off-diagonal terms to heat fluxes are identified in detail, i.e. the main ion heat diffusion are proved to be dominated by off-diagonal (diagonal) terms for region of weak (strong) ITG. In general, steep temperature gradients of main ions as well as hollow density profiles of impurity ions significantly enhance instability and heat fluxes. However, it is interesting to find that the effect of impurity ions with positive density gradient may transit from the enhancement to reduction of the quasi-linear heat flux of main ions in regions of steep ITG, corresponding to transport barriers (e.g. pedestal of H-mode and I-mode plasmas). Both strong and weak positive magnetic shear decrease heat transport.

The numerical investigations provide a new paradigm to understand the instabilities and induced heat transport in the presence of impurity ions, in particular considering regions of both weak and steep ITG, which corresponds to L- and I/H-modes plasmas, respectively. Such findings are certainly valuable for exploring the improvement of energy confinement of main ions and the mitigation of impurity accumulation. Recently, we also focus on the studies of turbulent transport induced by trapped electron mode, impurity ion density gradient driven mode, and coexistence of multiple modes. These subjects will be reported in the near future.

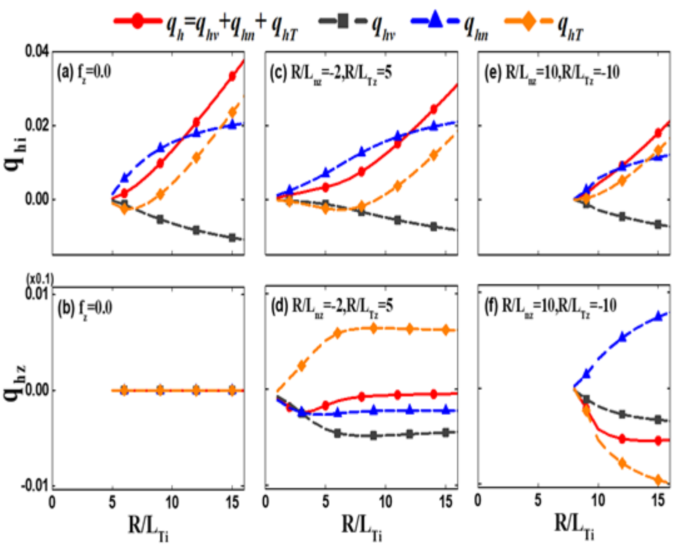

Figure 2. The heat flux q_{hs} of main and impurity ions and its components, including off-diagonal and diagonal diffusion flux (q_{hn} and q_{hT}) and non-diffusion flux q_{hv}.

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