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Theory of impurity effects on electromagnetic instabilities and the associative transport in the tokamak pedestal

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Recent experiment observes the anomalous transport in partial region of the pedestal. Kinetic ballooning mode (KBM) and Micro-tearing mode (MTM), which are electromagnetic turbulence driving anomalous particle and electron heat transport, respectively, have been widely observed in the pedestal of H-mode [1]. Moreover, non-trace impurity ions are known to affect instabilities in the pedestal [2]. Therefore, studying the impurity effects on KBM or MTM instabilities and the associative transport is beneficial for understanding pedestal physics.

From the electromagnetic gyrokinetic equation including the correction of strong radial electric field, the dispersion relationship of KBM instability with impurity and associated quasi-linear transport fluxes as well as the transport coefficients are derived based on the experimental parameters in the strong gradient pedestal of DIII-D [3]. Then, the parametric dependence of real frequency ω_r' and growth rate γ_k' of KBM instability, the impurity diffusivity D_z and effective ion heat conductivity χ_i^{eff} driven by KBM turbulence are analyzed [4]. Main conclusions are: 1) Dilution effects of impurity can reduce the drive of KBM through affecting the kinetic pressure gradient parameter α and diamagnetic effects, thus lead to the decrease of both $|\omega_r'|$ and γ_k', and stronger dilution effects by increasing the impurity charge number or steepening the impurity density profile correspond to stronger effects. 2) The ratio $\frac{D_z}{\chi_i^{eff}} \approx \frac{1-b_z+4\omega_{Dz}/\omega_r'}{3(1+1/\eta_i)/2}$, which reflects the removal efficiency of non-trace light fully ionized impurity (impurity mass number equals to twice of charge number, i.e. $A_z = 2Z$), increases with the increase of Z mainly due to smaller impurity finite Lamour radius (FLR) effects reflecting by $b_z \sim 1/Z$. Moreover, the increase of the impurity density gradient can significantly enhance D_z/χ_i^{eff}, and this is because stronger impurity dilution effects make a larger magnetic drift term $|\omega_{Dz}|/|\omega_r'|$ and η_i (the ratio between ion density gradient scale length to ion temperature gradient scale length). 3) For heavy metal impurity (such as tungsten) with concentration being 10^{-4}, its density profile is peaking inwardly, and the peaking factor decreases with the enhancement of impurity FLR effects. These results provide some theoretical reference on understanding the physical mechanism of impurity transport in the pedestal of H-mode plasmas.

Similarly, using experimental parameters [5] of the strong gradient pedestal region in DIII-D discharge in which observed MTM, the dispersion relation of MTM instability including impurity effects is derived based on the semi-collisional theory [6, 7]. From the analytical expressions, it is found that the dilution effect of impurities can increase collisional terms and decrease diamagnetic terms of MTM, modifying the linear characteristics. Moreover, the electron heat transport flux and transport coefficients are calculated using quasi-linear theory. Detailed results about the parametric dependence of MTM instability and the associated transport are still under analyzing.

References

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