Novel understanding of the role of plasma-molecular kinetics on divertor power exhaust: fusion meets low temperature plasma physics

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Power exhaust through divertor plasma detachment is a critical challenge for future reactors. Improving this through long-legged divertors in strongly baffled divertor chambers intensifies plasma-neutral interactions (MAST-U, TCV, STEP, SPARC, ARC). In such divertors, plasma-molecular collisions, as well as plasma chemistry, can play an important role.

We present a novel understanding of plasma-molecular kinetics through multi-device (MAST-U, TCV) studies, reduced models, and comparison against simulations. High resolution D_2 Fulcher band measurements allow extraction of the rovibrational distribution, providing information on energy/momentum transfer between the plasma and the molecules and plasma chemistry. A detailed study of the rotational temperatures in MAST-U (4000-9000 K) [3] and TCV (2000-5000 K), with different divertor shapes, baffling, heating and fuelling locations, indicates a correlation between the rotational and vibrational distribution. Our study shows that rotational temperature increases during deepening detachment depending primarily on the level of detachment. This is consistent with our reduced model as well as exhaust simulations: high neutral pressures combined with the longer lifetime of molecules in a detached divertor enable strong plasma energy/momentum dissipation through collisions – deepening detachment.

The vibrational distribution drives Molecular Activated Recombination and Dissociation (MAR/MAD), which can be critical in plasma detachment [1,2]. Previous work highlighted errors in the rates for these processes [1], causing MAR/MAD to be greatly reduced for deuterium plasmas, versus hydrogen plasmas, in simulations. New TCV studies disprove this isotope dependency - consistent with new collisional-radiative model predictions. This raises implications for the treatment of molecules in exhaust modelling and future reactor design.

References:

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