Contribution ID: **908** Type: **Regular Poster**

Investigating the role of plasma-atom/molecule interactions on power, particle and momentum balance during detachment

Wednesday, 12 May 2021 18:25 (20 minutes)

Executive summary: We report on the results of a quantitative study, based on experimental data, of the role plasma-atom and plasma-molecule interactions in power, particle and momentum balance during detachment. Important implications emerge for: 1) our understanding of detachment; 2) the interpretation of divertor spectroscopy measurements and 3) plasma-edge modelling, where the treatment of molecules may be immature. Our analysis of data from TCV shows detachment starts as the power required for ionisation approaches the power entering the ionisation region, limiting the ion source and thus the ion target flux. From that point onwards momentum losses, enhanced plasma-molecule interactions (with H_2^+ (and H^-)) and ultimately electron-ion recombination develop. The influence of these plasma-molecule interactions on power, particle and momentum balance are inferred to be significant compared to atomic interactions alone.

The development of detachment is affected by a range of atomic and molecular processes. There is currently no consensus regarding the relative importance of momentum and power loss, the role of molecular reactions nor the sequence of various processes observed during detachment. More specifically, it remains unclear whether the target ion current (I_t) reduction, observed during detachment, results from reductions in ion sources, increases in ion sinks, or both. In this work we investigate such issues experimentally through spectroscopy on TCV with emphasis on the effect of molecules.

For these investigations, we have developed and applied analysis techniques to the deuterium Balmer line emission, generating quantitative estimates of: (a) the atom-derived ion source and the related ionisation energy cost 1 (ion sinks/recombination have been addressed for over 20 years [2]); (b) the contributions of plasma-molecule interactions (with H_2^+ and H^-) to ion sources/sinks and hydrogenic radiative losses [3]. These techniques exploit the different sensitivities of each Balmer line to the various possible atomic and 'molecular'emission channels (H, H^+, H_2, H_2^+, H^-) to dissect each Balmer line into its emission channels and estimate the associated radiative loss and particle sink/source.

The results [4] of our analysis of a TCV core density ramp attaining detachment (see figure 1), indicate that, in the first detachment phase (red phase - target temperature, $T_t \sim 3-6$ eV), the observed saturation and decrease in It results from a saturation and reduction in the ion source. This is driven by both an increased energy cost of ionisation and a reduction in the power available for ionisation (due to increased upstream impurity radiation) [2,3]. As detachment develops further (green phase), the power available for ionisation decreases further, reducing T_t (≤ 1.5 eV) and increasing the electron-ion recombination (EIR, $< 15\%\ I_t$) ion sink. This is consistent with SOLPS modelling results [4,5] as well as analytic divertor modelling [4].

The bifurcation between the measured $H\alpha$ emission and its atomic estimate indicates plasma-molecule interactions with H_2^+ (and possibly H^-) are enhanced near the detachment onset, resulting in excited H atoms and atomic line radiation losses. Our analysis results (see figure 1) indicate these plasma-molecule interactions with H_2^+ (and possibly H^-) result in: 1) significant ion sinks ($< 35\%\ I_t$) through Molecular-Activated Recombination (MAR), which commence before EIR and remain higher; 2) excited atom radiation that can account for more than 50% of all hydrogenic line radiation; 3) significant enhancements to $n = 3-6$ Balmer lines (not shown). The emission enhancement for the $n = 5$ Balmer line (up to 30%) result in reduced ion source estimates in the deepest detached phase, compared to previous work 1 that only accounted for atomic contributions to the Balmer line emission.

At least on TCV, we thus conclude that the influence of plasma-molecule interactions (with H_2^+ and possibly H^-) on particle and power balance can be significant. This has important implications for interpretation of divertor Balmer line spectra as well as divertor modelling codes where the present treatment of molecules may be incomplete and incorrect. The isotope dependence of the reactions as well as their dependence on vibrational states may not be properly accounted for.

With the inclusion of ion losses through MAR, TCV's divertor particle balance implies an ion flow from upstream contributing to It in the deepest detached phases. This result will be compared further against SOLPS simulations [5] that indicate an increase in the ion flow from upstream towards the target during detachment. The MAR ion loss channel (in contrast to electron-ion recombination) leads to significant radiative losses. The implication of this (and the ion flow from upstream) will be investigated using analytic divertor modelling by extending the analytic Two Point Model (with Recycling - 2PMR [3]).

Excitation of H_2 through collisions between the electrons and H_2 occur in addition to reactions between the plasma and H_2^+ & H^- that lead to the MAR and atomic line radiation losses explored above. Such collisions can result in significant power and momentum transfer from the plasma to the molecules according to TCV and MAST-U SOLPS simulations [6,7]. Through measuring the molecular (H_2) band emission, we find that excitation through these collisions occur in different regions of the plasma than reactions with H_2^+ & H^-.

Our techniques allow the estimation of strength, sequence and spatial distribution of the various plasma-molecule interactions during detachment. Application to divertors of dissimilar divertor geometries/chambers (e.g. TCV and MAST-U) may be useful in providing insight as to how geometry modifies the relative roles of plasma-atom and plasma-molecule interactions in detachment.

[1] K. Verhaegh, et al. Plasma Phys. Control. Fusion (2019) 61 125018
[2] B. Lipschultz, et al. Phys. Plasmas (1999) 6, 1907
[3] K. Verhaegh, et al. Nucl. Fusion (2019) 59 126038
[4] K. Verhaegh, et al. to be submitted
[5] A. Fil et al, Plasma Phys. Control. Fusion (2020) 62 035008
[6] A. Smolders, et al. submitted
[7] O. Myatra, et al. to be submitted.

Indico rendering error

Could not include image: [404] Error fetching image

Affiliation

United Kingdom Atomic Energy Agency

Country or International Organization

United Kingdom

Primary authors: VERHAEGH, Kevin (CCFE); LIPSCHULTZ, Bruce (University of York); HARRISON, James (CCFE); DUVAL, Basil (Ecole Polytechnique Fédérale de Lausanne –Swiss Plasma Center (SPC)); FIL, Alexandre (Princeton University); Mr GAHLE, Daljeet (University of Strathclyde); Dr MOULTON, David (CCFE); Mr PEREK, Artur (Dutch Institute for Fundamental Energy Research); HENDERSON, Stuart (UKAEA); THEILER, Christian (EPFL-SPC); Dr THORNTON, Andrew (Culham Centre for Fusion Energy); Mr WENSING, Mirko (Ecole Polytechnique Federale Lausanne)

Presenter: VERHAEGH, Kevin (CCFE)

Session Classification: P4 Posters 4

Track Classification: Magnetic Fusion Experiments