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An exploration of a low temperature regime in EDGE2D-EIRENE simulations of JET ITER-like wall L-mode discharges

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1. Introduction

JET with its ITER-like wall (ILW) of Be in the main chamber and W in the divertor is ideally suited to gain understanding of the behaviour of the plasma edge and divertor, which is essential for predicting the performance of next-step machines such as ITER. Simulations by Groth *et al*. [1] of L-mode discharges run during JET-ILW campaigns and the previous JET-C campaigns, in which the plasma-facing surfaces were predominately C, have consistently shown a shortfall in the radiated power at low temperatures below that measured by bolometry, this bringing into question the predictions for the radiated power and cooling of a radiative divertor in a next step-machine. A similar result is found for unseeded ELMy H-mode discharges by Järvinen *et al*. [2]. A series of JET-ILW L-mode discharges, which reach detachment, provide a stringent test of the simulations in that most (~90%) of the radiated power from the divertor is due to atomic and molecular D, with impurities only playing a small role. In the present EDGE2D-EIRENE [3] simulations, the molecular contribution is, typically, only ~10-20% [4] and therefore plays a comparatively small role in the power balance. To investigate the atomic contributions to the radiated power, the simulations are compared with an independent atomic physics model, a preliminary model being available for He II. It is noted that the behaviour of D is very similar to that of He II, the D features occurring at a somewhat lower T_e (by ~2 eV). Of crucial importance is that the model used is complete and self-consistent.

2. Simulations

The EDGE2D-EIRENE simulations are based on the JET-ILW, L-mode simulations of Groth *et al.* [1]. They apply to a density scan series of 2.5MA / 2.5T discharges, pulses 81472 – 81492, heated with 1.1, 1.2 or 1.6 MW of NBI, which reach detachment. The simulation geometry is taken from discharge 81472, the fuel being D with Be and W impurities. A range of outer midplane separatrix densities 7×10^{18} m^{-3} up to the maximum at which the simulations converge of 2-2.2$\times10^{19}$ m^{-3} and powers transported across the separatrix into the SOL of 2.2-2.8 MW were considered. Little sensitivity to the power crossing the separatrix was found and hence the study has concentrated on the 2.2 MW simulations. The version of the EDGE2D-EIRENE code adapted to include D_2 and D_2^+ molecules was used allowing molecular radiation losses from the D_2 molecules to be quantified. The full reference atomic and molecular datasets were used as detailed by Kotov *et al*. [5]. The simulations use a diffusive transport model in which the radially varying particle and thermal diffusivities are illustrated in figure 9 of [1]. These were determined for the lowest density case, the same model being used for the higher density simulations. Ballooning transport and cross-field drifts are not included in the present simulations, although the latter are discussed by [6] and [7]. For the present cases drifts increase the radiated power by at most 30%, this decreasing with increasing density. To obtain results that fall in the low temperature regime the atomic and molecular power loss terms have been artificially increased as described by [4]. In that case the terms were increased using quadratic polynomials in T_e, but more control and flexibility is achieved by increasing the order of the polynomial used to quartic. By increasing the atomic power loss term by at most 4% in the temperature range 10-30 eV, T_e was reduced by up to ×10. In this way low temperature simulations were achieved and a series of cells along a flux surface (ring) selected in which T_e varied from 0.29-21.2 eV.

3 Atomic physics model

Stand-alone atomic physics models are being developed for D I and He II that include electron and heavy particle collisional excitation and deexcitation, radiative decay, direct collisional ionization, radiative and three-body recombination, these being the dominant populating channels for energy levels in these hydrogenic species (figure 1.) [8]. The models allow all components of the radiated power to be determined, particularly the total power and the line radiation from the 'spectroscopic' levels, those within the n=1-5 shells (with n the principal quantum number), which can be directly compared with experiment. Indeed the Ly-α radiation is expected to account for ~85-90% of the power radiated by these hydrogenic atoms over a wide temperature range. A J-resolved description (J the total angular momentum) is used for the spectroscopic levels and n-resolution for higher shells up to the maximum considered of n=16. This is above the collision limit for these species at all densities of interest, the collision limit being the n shell above which the probability of the atom being ionized exceeds 50%. At present, the He II model is being tested. T_e, n_e, n_D, n_{D+} from the simulations are interpolated to the temperatures used by the model (figure 2) and then used as inputs to the model.

4 Results

Figure 3 compares the radiated power due to atomic D taken directly from the simulation with results from the He II model. Different populating channels can be readily switched on or off in the model and it is found that removing radiative recombination as a populating mechanism makes comparatively little difference, since three-body recombination has a much larger effect, this channel strongly feeding the high *n* shells. At present it is not known whether this effect is overestimated, which leads to uncertainties in the model results at the lowest temperatures. Nevertheless, the model clearly show an increase in the radiated power below T_e ~3 eV as recombination plays an increasing role in populating the excited levels. In contrast, the output from the simulations show a steep fall below T_e ~1 eV. To mimic this in the model it is necessary to switch off both radiative and three-body recombination populating channels and to remove the radiation directly due to radiative recombination from the D radiated power; that is in this version of EDGE2D-EIRENE, although there are recombination source terms, these are not reflected in the power radiated by atomic D. Inclusion of the radiation due to radiative recombination in the simulation significantly reduces the discrepancy (figure 4), although does not eliminate it, at least in this D simulation / He II model comparison.

Recombination is described in EDGE2D-EIRENE in terms of a recombination-bremsstrahlung power coefficient, PRB [9], which determines the components to the radiated power and changes to the energy loss term. However, combining these processes into a single term creates a difficulty in that bremsstrahlung and radiative recombination result in an electron energy loss (if recombination is to the ground state this is simply the kinetic energy of the recombining electrons), whereas the non-radiative three-body recombination an energy gain. Three-body recombination is the reverse process to collisional ionization with an energy loss on ionizing from the ground state of the D ionization potential, I_H, and a corresponding energy gain of I_H for three-body recombination to the ground state.

5 Conclusions

A strong dependence of the atomic power loss terms in EDGE2D-EIRENE simulations on T_e has enabled a low temperature regime to be accessed, allowing a comparison with a preliminary stand-alone atomic model. This shows that, in the version of EDGE2D-EIRENE being used, recombination does not contribute to the D radiated power. Work is in progress to understand this result and including recombination effects in the radiated power should largely account for the radiated power discrepancy found at low temperatures in these simulations.

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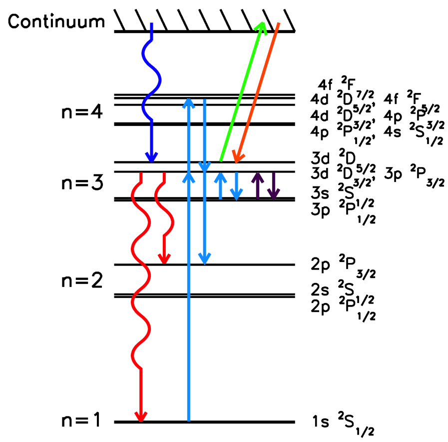

Figure 1. Schematic diagram of the hydrogenic energy levels showing populating and depopulating channels. These include radiative decay, electron and heavy particle collisions, direct collisional ionization, radiative recombination and three-body recombination.

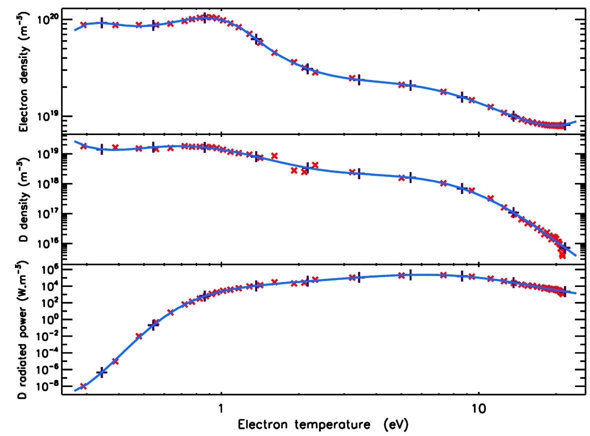

Figure 2. × D simulation output of $n_e \approx n_{D+}$, n_D, D_{Prad} from cells along a flux surface, showing interpolations and + points used as inputs for the model or for a comparison with P_{rad}.

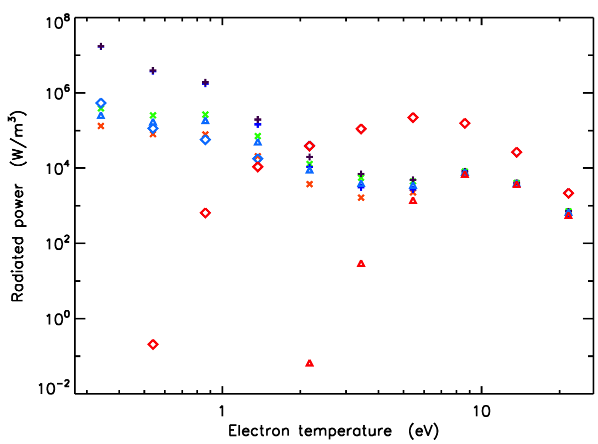

Figure 3. D radiated power from ◊ D simulation, ◊ including radiative recombination radiation, + He II population model, + including radiative recombination radiation, × population model excluding 3-body recombination rates, × including radiative recombination radiation, Δ population model excluding radiative and 3-body recombination rates, Δ including radiative recombination rates.

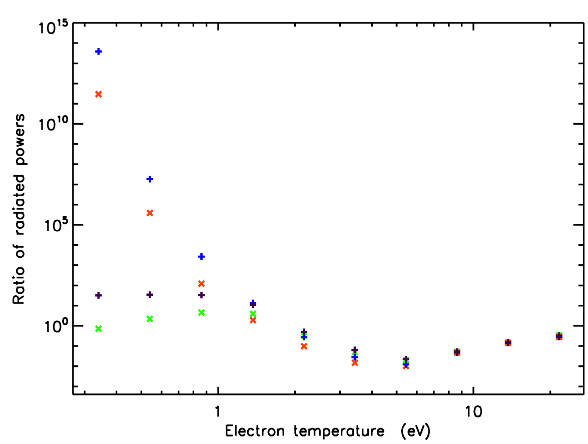

Figure 4. Ratio of modelled to simulated radiated powers. + He II population model, + including radiative recombination radiation, × population model excluding 3-body recombination rates, × including radiative recombination radiation.