Summary, Conclusion, and Outlook

In order to investigate the diagnostic potential of fast He beams, extensive modelling calculations have been performed for a fast He beam penetrating a plasma which resulted in the progression of He ground state- and metastable-states populations and the related intensity profiles of visible HeI lines. The calculations are based on the collisional-radiative model for He beams developed by the ADAS group at the University of Strathclyde, Glasgow [1]. We used typical electron density- and temperature profiles from ASDEX Upgrade and JET. He beam energies of 30 keV (AUG) and 80 keV (JET) were chosen to match those used for first experiments at these tokamaks. Calculations have been performed for the extreme cases of incident pure ground state- and pure 2^3S beams, respectively. The results for realistic beams with an initial metastable fraction between these extremes can be determined by mixing the two results with the corresponding weight factors. The calculations showed that the 2^1S-population density is strongly coupled to the 1^1S-population density, whereas the 2^3S-level is preferably populated in regions with low electron temperature (near the outer and inner separatrices), but strongly depopulated in the hot core. In an initially pure ground-state beam the 2^1S fraction reaches about 10^{-4} near the separatrix and drops slightly inside the core, whereas the 2^3S fraction reaches 10^{-5} (JET) or 10^{-4} (AUG) near the separatrix and drops by about one order of magnitude in the core. For an initially pure 2^3S beam the progression of the 2^1S-population density is dominated by the 2^3S-population density in the region where the 2^3S concentration outnumbers the ground-state concentration. The line-intensity profiles of both spin systems resemble the corresponding metastable population-density profiles.

The attenuation of a 80 keV He beam penetrating a hot, dense and rather large JET H-mode plasma is much weaker than that of a 30 keV He beam injected into a cooler and less dense ASDEX Upgrade L-mode plasma with its considerably smaller dimension. In the case of AUG, the beam composition reaches equilibrium after about 0.3 m and becomes independent of the initial beam composition. The initial beam composition is therefore unimportant for the emission from the plasma core. In the case of JET, the 2^3S-fraction does not reach saturation. Here, at each position along the path of the beam its composition is still influenced by the initial composition.

In order to assess the potential of He-beam emission spectroscopy as useful plasma temperature and -density diagnostics, we have examined the sensitivity of visible HeI lines with respect to n_e and T_e. The calculations were performed for an 80 keV He beam penetrating a JET discharge which develops an internal transport barrier.

Basically all singlet lines are rather sensitive to density variations. The sensitivity is highest in the edge and drops towards the plasma center. The 502 nm-, 668 nm-, and 492 nm lines are the most sensitive ones with respect to density and show only small variations in both edge- and core region. In the case of a pure ground-state beam the singlet lines are more sensitive with respect to temperature variations than to density variations in the outermost edge region, but this temperature sensitivity is dramatically reduced towards the separatrix and inside the core. An increase in the initial 2^3S fraction results in a strong decrease in the temperature sensitivity of all singlet lines in the plasma edge - the lines at 492 nm and 668 nm lose their sensitivity to T_e almost entirely. Additionally to its favourable sensitivity to n_e and relatively small sensitivity to T_e, the 668 nm line is also the strongest singlet line. This makes the 668 nm line the prime candidate for n_e measurements. If the sensitivity of the optical system can be enhanced, also the 492 nm line would be suitable.

To deduce T_e profiles from line emission profiles, lines which are mainly sensitive to T_e would be desireable. Some of the triplet lines are rather sensitive to T_e for an initially pure ground-state beam. This sensitivity decreases strongly with increasing initial 2^3S fraction. The singlet line at 728 nm shows as well a relatively strong sensitivity to T_e. Unfortunately, none of the lines is mainly sensitive to temperature as all lines have a high sensitivity to density. The 389 nm line is the most sensitive one with respect to T_e, with a sensitivity of about 60% in the outermost part of the plasma edge, i.e. a 100% increase in temperature results in a 60% increase in emission intensity. This is reduced to a 20% sensitivity in the plasma center. The favourable sensitivity to density together with the 'stiffness' of temperature profiles observed in various tokamak experiments should result in a good first approximation for the density profile from the 668 nm emission profile. If this density profile is sufficient, it will permit the calculation of an improved temperature profile from the 389 nm line emission profile. This procedure can be iterated and is expected to converge to a selfconsistent solution.

To validate the model calculations, data have been considered from experiments with fast He beams and beam emission spectroscopy performed at ASDEX Upgrade and JET, making use of the respective neutral beam heating systems. The intensities of the He-beam emission obtained from either experiment are sufficiently large to permit meaningful measurements with both HeI singlet- and triplet lines in the plasma. Comparison between measurements and model calculations shows a favourable agreement.

The calculations performed in this thesis and preliminary experiments at tokamak plasmas guided by these calculations have confirmed that fast He beams may serve for a useful plasma temperature- and -density diagnostics.

Recently, a new version of the collisional-radiative ADAS model has been developed which treats all levels up to n=5 as non-equilibrium levels. This work is going on and should allow for still more accurate calculations, especially for large plasma-parameter gradients. It is also intended to improve and update the fundamental atomic collision data in ADAS, which should lead to a better accuracy of the here derived density- and temperature profiles.

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