On the applicability of fast neutral He beams for fusion plasma diagnostics

PhD thesis

by

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Abstract

Precise knowledge of plasma temperature- and -density profiles in experimental fusion plasmas is a prerequisite for satisfactory understanding and modelling of plasma confinement. The photon emission from fast lithium beams has been successfully used for the measurement of density profiles in the scrape-off layer. From the photon emission of thermal helium beams, electron density- and -temperature profiles can be deduced. Both, thermal helium- and fast lithium beams, have a penetration depth limited to the scrape-off layer of plasmas. By using fast helium beams with a much deeper penetration it is expected to also extend the range of measurements deeper into the plasma.

Fast neutral helium beams can be produced by neutralizing an accelerated helium-ion beam by collisions with a target gas. After this neutralization process a fraction of the helium atoms is in the metastable states. Atoms in metastable states have much higher cross sections for processes relevant in fusion plasmas than those in ground state. The first part of this thesis is therefore devoted to the production and characterization of so-called mixed beams, i.e. beams with a sizeable metastable fraction. These experiments were carried out at the Institut für Allgemeine Physik (IAP) using an existing 2.45 GHz ECR ion source. Helium-ion beams of up to 12.5 keV energy have been produced and subsequently neutralized in sodium vapour and/or helium gas. The beam composition was measured spectroscopically by a neon-gas filled attenuation chamber using the emission of either a NeI line (633 nm) or a HeI line (389 nm). Helium beams with metastable fractions of up to about 80% could be produced.

In the second part of this thesis the potential of helium beam emission spectroscopy as diagnostic tool is investigated by modelling the photon emission of a helium beam penetrating typical fusion plasmas. The calculations are based on a collisional-radiative model developed by the ADAS group at the University of Strathclyde, Glasgow. The code SCOTTIE, written at IAP in ANSI/C, solves the differential balance equation of the He-beam flux and -composition on its way through the plasma. By using typical temperature- and density profiles from ASDEX-Upgrade and JET, the photon emission profiles are calculated taking the metastable triplet fraction as a free parameter. From these modelling calculations the sensitivity of the method with respect to electron density and -temperature can be extracted. The photon emission at some visible lines is mainly sensitive to the plasma density, with only weak dependence to electron temperature. Other lines show a higher temperature sensitivity of the order of 20%, i.e. a 100% increase in temperature results in a 20% increase in emission intensity. It is expected that both temperature- and density profiles can be derived iteratively from measured photon emission profiles using suitable HeI lines.

In the last section of this thesis the modelling calculations are applied to Helium-beam emission profiles measured at ASDEX Upgrade- and JET Plasmas. Comparison between measurement and modelled photon-emission profiles, calculated from density- and temperature profiles taken from other diagnostics, shows a promising agreement.

The calculations performed in this thesis and the preliminary experiments at tokamak plasmas seem to confirm that fast He beams may serve for useful plasma temperature and -density diagnostics in a much larger plasma region than the one covered by lithium- or thermal helium beam diagnostics. However, appropriate methods to derive temperature- and density profiles from such measured HeI-emission profiles still have to be developed.

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