Topic number: 9

Transport of charged particles in the magnetic filter field of RF sources for the production of negative hydrogen ions

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The neutral beam injection system foreseen for heating and current drive at ITER is based on the generation, acceleration and neutralization of negative hydrogen ions. In 2007 the RF driven negative ion sources developed at IPP Garching [1] was chosen as the ITER reference design.

In these ITER relevant ion sources negative ions are produced by the so-called surface process: hydrogen atoms or positive ions are converted to negative ions by picking up electrons from metallic surfaces with sufficiently low work function. To achieve this, the inner surfaces of the ion source are covered with a thin cesium layer.

The source design is based on the tandem concept: in the cylindrical driver region a dense ($n_e \geq 10^{18}$ m^{-3}) and hot ($T_e \geq 15$ eV) plasma is generated which then flows into the expansion region. Here the plasma is cooled down by means of a magnetic filter field to electron temperatures below 2 eV close to the extraction system. Additionally, the plasma density is reduced by one order of magnitude. The reduced temperature and density result in a low collision frequency for destruction of the negative ions close to the extraction system and thus a survival length in the order of several cm. Hence, only negative ions produced on the surface of the plasma grid (which is the first grid of the three grid extraction system) are relevant for extraction.

In the IPP prototype ion source (⅛ ITER area of the extraction system) the magnetic filter field is generated by rods of CoSm permanent magnets. In future larger negative ion sources like ELISE [2] (half ITER area) or SPIDER [3] (full ITER area), the filter is generated by a current flowing through the plasma grid.

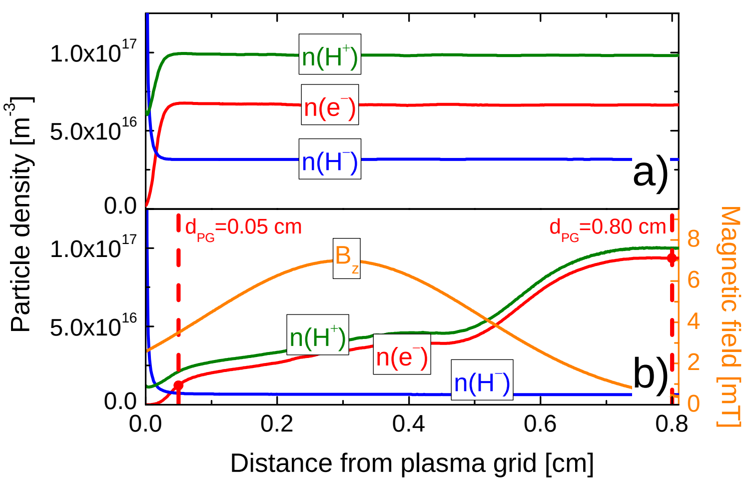

Fig. 1 Calculated particle densities close to the plasma grid.
a): no magnetic field;
b): magnetic field, elastic, inelastic and Coulomb collisions.

Up to now the complex interplay of processes involved in the functionality of the magnetic filter is not fully understood; hence a 1d3v PIC-MC [4] code was applied to the transport of plasma particles and surface produced negative ions across a magnetic field in the close vicinity of the plasma grid surface. Measured plasma parameters and the typically used magnetic field strength of the IPP prototype negative ion source are used for a reduced calculation domain.

The Monte Carlo module is based on the cumulative small angle method (Coulomb collisions) [5], the null collision method (elastic and inelastic collisions) [6] and the Boris scheme (motion of charged particles in the magnetic field).

Previously, for small calculation domains (x<<1cm) it was shown that the emission of negative ions into the plasma volume is space charge limited [7]. Changes in the proton density caused by the filter field strongly influence the emission of negative ions into the plasma volume. Additionally, it was shown that the electron transport through the filter field is based on collisions; the most relevant collision process are elastic collisions [8].

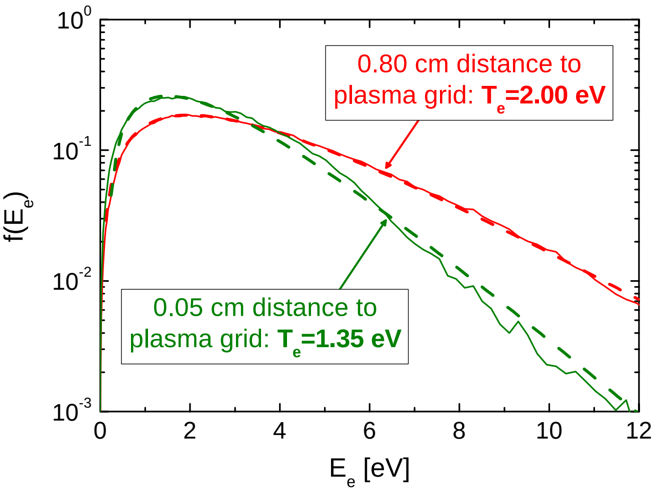

Fig. 2 Calculated EEDF in front of and behind the magnetic filter; Maxwellian EEDF for T_e=2.0 eV and 1.35 eV.

To investigate the mechanisms responsible for cooling of electrons in the magnetic filter, calculations were performed for a larger calculation domain (x≈1 cm). The initial temperature of electrons injected into the calculation domain is 2 eV.

Figure 1 shows profiles of particle densities with and without the magnetic field. Due to a very small gyro radius (r_L is in the order of 1 mm) electrons are trapped in the magnetic filter. The maximal displacement of electron trajectories by single collisions with plasma particles is in the range of one gyro radius only; thus the time of flight for electrons traversing the filter is significantly longer than with no present magnetic field.

During that time, electron cooling occurs by a combination of coulomb collisions (velocity dependent cross section) and sudden energy loss during inelastic collisions. Figure 2 shows EEDF calculated before (distance from plasma grid=0.80 cm) and after the (distance=0.05 cm) electron transport through the filter. Also shown are Maxwellian EEDF for 2.0 eV and 1.35 eV. Even though a reduced calculation domain is used, a significant cooling of the electrons in the filter field is observed. This finding is in good qualitative agreement with experimental results. The calculated EEDF behind the filter slightly deviates from a Maxwell distribution function.

The PIC-MC code will be introduced; results of the calculations will be presented and the relevance of Coulomb and inelastic collisions will be discussed.

Reference

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