INVESTIGATION OF THE ELECTRON DISTRIBUTION FUNCTIONS IN LOW PRESSURE ELECTRON CYCLOTRON RESONANCE DISCHARGES

I. KAGANOVICH, M. MISINA, A. BOGAERTS, R. GIJBELS
Department of Chemistry, University of Antwerp, Universiteitsplein 1, B-2610 Wilrijk, Belgium

The interest in low pressure electron cyclotron resonance (ECR) discharges is motivated by the wide use of these discharges in plasma-aided materials processing and as a source of highly charged ions. The electron distribution function (EDF) is far from Maxwellian in these discharges and has been subject of many investigations. For calculation the EDF in ECR discharges we present in this paper the electron Boltzmann kinetic equation (0D in space and 1D in energy) averaged over fast electron bouncing and over collisions. A similar procedure was applied to capacitively coupled plasma in Ref. 1, where a wide range of discharge parameters was explored. The validity of the fast modelling (FM) method is proved by comparison with Monte-Carlo simulations (1D in space and 2D in velocity).

We start from simplified equations in drift approximation. Making transformation from $v_{\parallel},\mu$ to longitudinal energy $\varepsilon_{\parallel} = 0.5mv_{\parallel}^2 - e\Phi(x) + \mu B$ and $\mu = mv_{\perp}^2/2B$, which is proportional to magnetic moment, the kinetic equation reads:

$$v_{\parallel}\left.\frac{\partial f}{\partial x}\right|_{\varepsilon_{\parallel}} = St(f) + St^{*}(f) + St^{ECR}(f) \tag{1}$$

where f is a distribution function in velocity space, $\parallel$, $\perp$ symbols denote direction along and perpendicular to magnetic field, respectively, $\Phi(x)$ is a stationary ambipolar potential in plasma, $St(f)$, $St^{*}(f)$ are the integrals for elastic and inelastic collisions with atoms, respectively, $St^{ECR}(f)$ is the integral describing electron interaction with the wave electric field in the resonance point. Passing through resonance, the electron randomly changes the perpendicular velocity with kick amplitude $\Delta v_{\perp 0} = (eE\sqrt{2\pi})/(m\sqrt{v_{\parallel}\left|\frac{d\omega_B}{dx}\right|})$, where E is the amplitude of circular polarized wave in resonance point $\omega = \omega_B \equiv eB/mc$. $St^{ECR}(f)$ can be modelled by the diffusion in perpendicular velocity or in magnetic moment: $v_{\parallel}\delta(x - x_r)\frac{\partial}{\partial\mu}D_{\mu}\frac{\partial f}{\partial\mu} = St^{ECR}(f)$,

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$D_\mu = 0.5 < (\Delta\mu)^2 >= \frac{m\mu e c E^2}{B} \frac{\pi}{v_{II}\left|\frac{dB}{dx}\right|}$. We consider a low-pressure discharge where the bounce frequency is larger than the collision frequency. In this case, l.h.s. of Eq.1 is large. Integrating Eq.1 by $\oint \frac{dx}{v_{II}}$ we perform averaging over fast electron bouncing and the EDF becomes a function of two arguments only, $f(\varepsilon_{\|}, \mu)$, and does not depend on x. For the main part of EDF, i.e. for the energies smaller than 50 eV, the elastic collision frequency is much larger than the inelastic one. It results in the formation of an isotropic EDF, which now depends only on a single argument - total energy $f(\varepsilon)$. This result was confirmed by MC simulations, see Fig.1 . After averaging Eq.1 reads:

$$-\frac{d}{d\varepsilon} D_\varepsilon \frac{df}{d\varepsilon} = \overline{St^*(f)} \qquad (2)$$

where averaging is produced by: $\overline{G} = \int_{x(\varepsilon)}^{x_-(\varepsilon)} dx \int_0^{\sqrt{2\varepsilon/m}} dv_{II}$, $D_\varepsilon = \frac{1}{3} \frac{2V^3 \varepsilon^2}{\sqrt{2\varepsilon/m}}$, and $V^3 \equiv 2\pi(eE)^2 /(m^2 \left|\frac{d\omega_B}{dx}\right|)$.

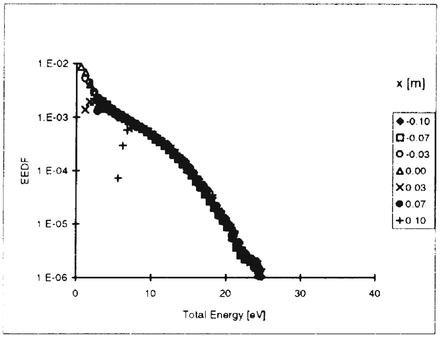

Figure 1 The results of MC calculations: isotropic EDF as a function of total energy at various spatial positions x .

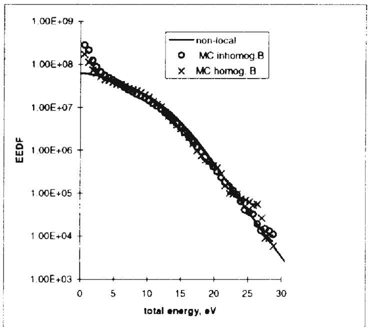

Figure 2 Comparison of FM (solid line) and MC simulations: circles correspond to magnetic field $B(x)=B_0\,(1+2/\pi\ \mathrm{arctn}(-x/x_0))$ $B_0=0.0875$ T, $x_0=80$ cm, crosses correspond to $B(x)=B_0$.

A comparison of the EDF calculated from the averaged kinetic equation and by the MC method is shown in Fig.2. The Eq.2 reveals that, for a given value of velocity kick in ECR, EDF is not a function of the spatial profile of the magnetic field. The results of MC calculations prove this finding, see Fig.2.

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1. S.V. Berezhnoi, I.D. Kaganovich, L.D. Tsendin, (1998) Plasma Sources Sci. Technol., 7 268-281.