# A KINETIC MODEL OF A SCRAPE-OFF LAYER WITH RECYCLING

R. Chodura

Max-Planck Institute für Plasmaphysik,
EURATOM Association, D-8046 Garching, Fed. Rep. of Germany

## Abstract

A 1d particle model with a Fokker-Planck collision term is used to describe the energy flow in a scrape-off layer with particle recycling. Hot particles from the core plasma and relatively cold recycled particles from the target plate form a velocity distribution with a low energy maxwellian bulk distribution and a tail in target direction of energetic particles which cannot be maxwellized within the path length along the layer. The energy flux is mainly carried by these tail particles, whereas the other flow quantities are determined by the bulk particles.

## Introduction

In toroidal plasma configurations the core of closed, nested magnetic surfaces is surrounded by a scrape-off region, where magnetic field lines end on material walls, i.e. limiters or divertor plates. Particles and energy, diffusing perpendicularily to the magnetic field out of the core into the scrape-off layer flow there mainly parallel to field lines to the target plates. Plasma ions reaching the target are recycled as cold neutrals and eventually become reionized. Thus a cloud of cold plasma in front of the target is formed. The energy flux along the scrape-off layer has to provide the energy for ionization and heating of the recycled partices, for the kinetic energy of the ions and for the energy of some electrons to overcome the potential barrier of the sheath at the target.

The scrape-off layer contains hot core particles as well as relatively cold recycled particles. The hot core particles may have mean free path lengths for relaxation which are comparable or larger than their path lengths from the place of their appearance in the scrape-off layer to the target plate. The velocity distribution of these particles is thus expected to be strongly non-Maxwellian. The relatively cold particles, on the other hand, have mean free path lengths of a small fraction of their total path length and are Maxwell distributed. A kinetic model is thus demanded to describe the relaxation process between hot and cold particles and the energy flux along the scrape-off layer.

## Model

The numerical model is a 1d electrostatic particle-in-cell code for the plasma electrons and ions including a Fokker-Planck representation of the velocity change by Coulomb collisions [1]. The magnetic field is assumed perpendicular to the target plate along x (Fig. 1). The particle flow originates from a source of hot particles with temperature $T_i = T_e = T_h$ near the symmetry plane x=0. Ions reaching the target plate at $x = L$ are redeposited as cold electron-ion pairs with $T_i = T_e = 0$ in front of the target plate. An amount of energy representing the ionisation energy of the recycled particles is withdrawn from the already existing electrons.

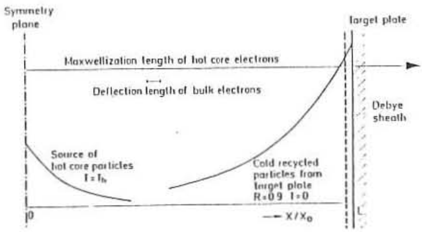


Fig. 1: Schematic situation of a 1d scrape-off layer with recycling.

The code resolves the electrostatic Debye sheath. In a real scrape-off layer the sheath thickness $\lambda_s$ is 4-5 orders of magnitude smaller than the mean free path lengths $\lambda$ of bulk particles and even more orders of magnitude smaller than the lengths L of the layer. In order to keep these quantities in scale $\lambda_s$ was artificially enlarged relative to $\lambda$ and L. Thus, as in reality,

$$\lambda_s \ll \lambda \ll L \leq \lambda_h$$

where $\lambda_h$ is the mean free path length of hot core particles, but the numerical relation of $\lambda_s$ to the other quantities is unrealistic.

## Results

Figure 2 shows steady-state profiles of flow quantities and electric potential over x for a hydrogen plasma. Hot core particles are fed in at constant rate near x=o with an e-folding length 5 at a temperature $T_h = 10$ (in arbitrary units). Ions reaching the target are recycled with an recycling coefficient R=0.9 as electron-ion pairs over a e-folding length of 20 in front of the target plate at L=80. An ionization energy of $W_{ion} = 0.4$ is withdrawn from background electrons. The source distribution determines the particle flux $\Gamma$. The other curves of Fig. 1 show density n and mean velocity V of ions and electrons (which differ only in the sheath) together with the isothermal sound speed $C = [(T_i + T_e)/m_i]^{1/2}$. At the sheath edge V=C. Electron and ion "temperatures" (parallel and perpendicular to the flow direction, $T_{\|}$ and $T_{\perp}$ respectively) are much lower than $T_h$ of source particles. The energy input of electrons or ions in the source, $Q_h = \frac{3}{2}\Gamma_h T_h = \frac{3}{2}0.00233 \cdot 10 = 0.035$ is mainly transported as heat flux $q = \frac{m}{2} \cdot \langle (v-V)^2 (v_x - V_x) >$ in the pre-recycling region and is partly transformed in ionization energy rate, convective and ion kinetic energy flux in the recycling region.

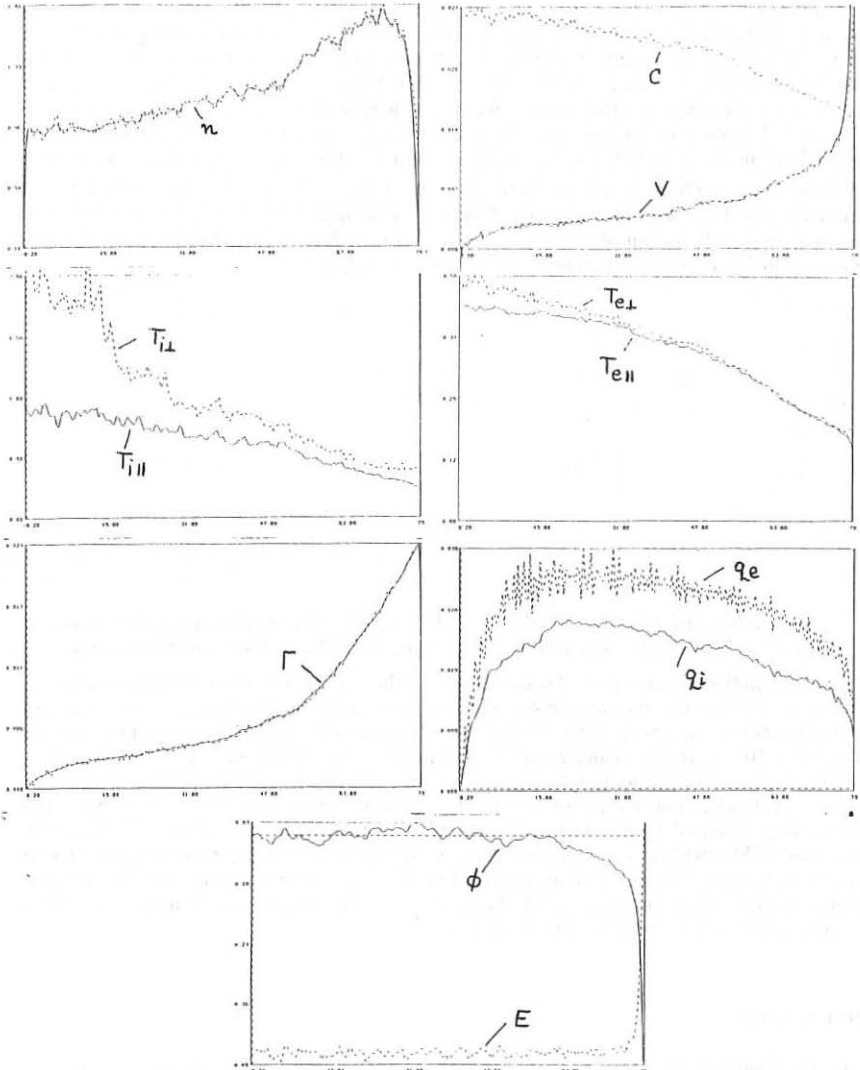


**Fig. 2: Density $n$, mean velocity $V$ and isothermal sound speed $C$, temperatures $T_{\|}$ and $T_{\perp}$ parallel and perpendicular to the flow direction for ion and electrons, particle flux $\Gamma$, heat flux $q$, potential $o$ and electric field $E$ as function of $x$ for steady state.**

The energy transport of electrons and ions through the scrape-off layer is characterized by a velocity distribution of relatively cold Maxwellian bulk particles and a tail in the direction to the target of energetic particles from the hot source. This is shown in Fig. 3 for the ion and electron distribution $F(v_x) = \int\int dv_y dv_z f(v_x, v_y, v_z)$ at 4 locations x on a logarithmic scale. Source particles with their thermal velocity $v_{th} = (T_h/m)^{1/2}$ have a mean free path length for energy transfer to bulk particles of the same kind of $\lambda_h = 5 \cdot 10^2$, i.e. much larger than L. Since $\lambda_h \propto v^4$, only particles with velocities $v < 0.63 v_{th} = 2.0$ for electrons and 0.05 for ions can be thermalized to the bulk temperature within the system length L. This limit can clearly be recognized by inspecting the deviation of the distribution $F$ from a Maxwellian (of the same density, mean velocity and temperature). For bulk particles $\lambda \sim 4$.

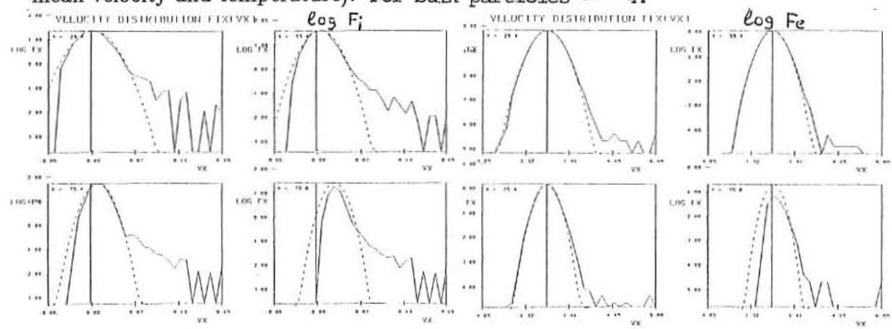


Fig. 3: Ion and electron distributions $F(v_x) = \int\int dv_y dv_z f(v_x, v_y, v_z)$ at 4 locations x = 29.4, 59.4, 75.4, 79.8 and corresponding Maxwellians (dashed lines).

Only thermalized source particles contribute to the heating of the cold recycled plasma, whereas the fast tail particles move more or less freely to the target plate. The tail particles contribute very little to the low moments of the distribution, i.e. density $(n_h/n \sim 10^{-3})$, mean velocity and temperature, but carry most of the heat flux $q$. Thus, in the situation at hand no local or non-local relation between heat flux $q$ and temperature gradient $\nabla T$ is applicable. The potential drop $\Delta o_s$ over the sheath is not noticeably changed by the tail in the electron distribution, i.e. $e\Delta o_s = 2.8 T_{es}$ as in the case of Maxwellian electron distribution, where $T_{es}$ is the electron temperature at the sheath edge. But the elctron energy flux $Q_{es} =< \frac{1}{2} m_e v^2 v_x >$ at the sheat edge is significantly larger, i.e. $Q_{es} = \delta_e \Gamma_s T_{es}$ with $\delta_e = 7.6$, as compared to $\delta_e = 4.8$ for a purely Maxwellian electron distribution [2].

## References

/1/ R. Chodura, 12th Europ. Conf. on Contr. Fusion and Plasma Physics, Budapest, Europhysics Conf. Abstracts 9F, Part II, p.472 (1985).

/2/ P.C. Stangeby, J. Nucl. Mat. 128&129, 969 (1984).