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THE REDUCTION OF DIFFUSION BY PLASMA ROTATION AND ION DISSIPATIVE EFFECTS

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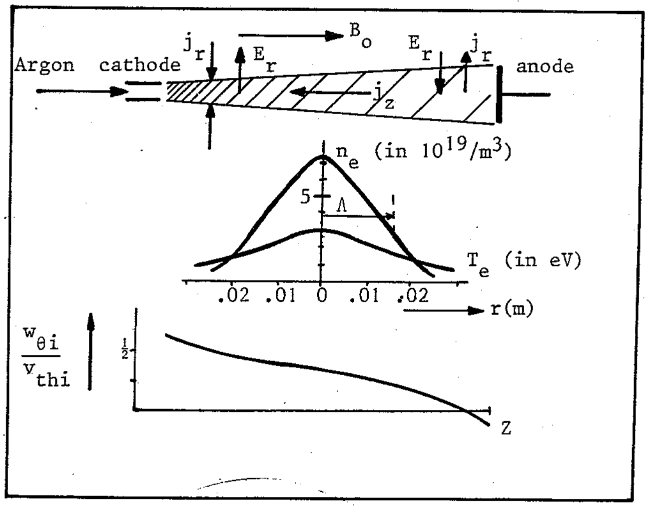
Introduction.

Many studies have been conducted on particle transport and pressure enhancement in magnetized arcs [1]. The magnetic field reduces the transverse electron heat conduction and particle diffusion (at least classical), leading to higher axisvalues of T_e and n_e. In addition the Nernst effect reduces also the particle transport [1].

In many of these treatments the effects of ion-viscosity and ion-neutral friction have been ignored. Klüber [2] realized, that in these arcs rotational velocities are relatively large and may even approach the ion thermal velocity $\frac{2kT_i}{M_i}$; the rotation (caused by radial electro field E_r) is connected with the presence of radial current. At the cathode it tends to be positive ($E_r < 0$, directed inward), at the anode negative ($E_r > 0$); the exact potential distribution depends also on geometry (cf. fig. 1). We will show that the combined effects of rotation and ion-viscosity and ion-neutral friction can reduce the particle transport substantially for positive rotation (cathode side and in our case for most of the arc length) and can enhance the transport for negative rotation (close to the anode). Consequently, there exists a weak axial gradient even in a cylindrical geometry with identical electrodes : at the cathode the plasma is hotter and more dense than at the anode. It is the aim of this contribution to show, as well theoretically as experimentally that because of these effects the particle confinement may be appreciably better than "Nernst classical", i.e. classical including the Nernst-effect; in many cases the pressure-built up can be explained by the rotational confinement rather than by the Nernst effect.



Theoretical prediction.

We have investigated elongated quasi-cylindrical arcs with axial dimensions (typical gradient length L) much longer than radial dimensions (Λ). The rate of the two scale lengths is supposed to be in the order ot the Hall parameter $\Omega_e\tau_e$, which is supposed to be large ($L/\Lambda \sim \Omega_e\tau_e >> 1$; Ω_e, electroncyclotron frequency; τ_e, electron-ion collision time). The radial diffusion velocity, w_{ri}^{cl}, is much smaller than rotational velocity, $w_{\theta i}$. If we assume [3], that the radial electric field is in the order of the temperature over the radial scale length Λ: $E(\Lambda) \sim \frac{kT}{e\Lambda}$, we can estimate $w_{\theta i}$ to be : $w_{\theta i} \sim a(r) r\Omega_i$, with $a(r) \sim v_{thi}^2/\Lambda^2\Omega_i^2$. Furthermore, with $w_{ri} \sim b(r) r\Omega_i$, one can show that for classical diffusion $w_{ri}/w_{\theta i} = b(r)/a(r) \sim 1/\Omega_e\tau_e$.

The analysis of the momentum equations for ions and electrons with systematic ordering in $1/\Omega_e\tau_e$ and λ_{ii}/Λ ($\lambda_{ii} = v_{thi}\tau_i$), yields the following diffusion flux [3]:

$$nw_{ri} = \frac{1}{\Omega_e\tau_e eB_o(1+2a)} \left\{ \left[\frac{nm_i\, w_{\theta i}^2}{r} + \frac{\partial}{\partial r}(p_e+p_i) - \frac{3}{2} n \frac{\partial kT_e}{\partial T} + j_z B_\theta \right] - \Omega_e\tau_e \left[(\nabla_i \underline{\Pi}^i)_\theta + R_\theta^{ia} + M_\theta^S \right] \right\}$$

The second term contains contributions of viscosity $(\nabla . \underline{\Pi}^i)$, ion neutral friction, R^{ia}, and momentum transfer connected to a finite source term M^S; we consider the case $\Omega_i\tau_i \leq 1$.

In the experimental case considered, we may neglect the pinch- and ion-terms in the first term of

nw_{ri} which can be written as $nw_{ri}{}^{Cl} = D^{Cl} \frac{\partial n}{\partial r}$ with classical diffusion coefficient $D^{Cl} = \frac{kT_e}{e\, B_o\, \Omega_e \tau_e}$. The second term of nw_{ri} "rotational diffusion", is multiplied by $\Omega_e \tau_e$ and can be very large. All three contributions depend on $w_{\theta i}$; if the ion rotation is positive (cathode side) the rotational diffusion is inward, if it is negative then the diffusion is outward. For our experimental conditions (and the estimate of $w_{\theta i}$ as above), the rotation-viscosity contribution and the ion-neutral friction are in the same order as classical transport [3].

Anomalous diffusion.

For large values of $\Omega_e \tau_e$ and B_o we observe also a high level of turbulence. These fluctuations ($k \sim 1/\Lambda$) may give rise to anomalous (Bohm) diffusion and *enhance* the transport. The anomalous diffusion coefficient, D^{an}, can be estimated as : $D^{an} = D^{Cl}\ \Omega_e \tau_e\ (\frac{\tilde{n}}{n})$, if we ignore here the effect of rotation.

The turbulence level is measured [4] by probing the plasma-light-fluctuations with two photodiodes ($f < 1$ MHz). Of the three classes of observed waves (rotational instabilities, drift waves, ion waves, all propagating transverse to B_o) we assume that the drift waves are mainly responsible for the anomalous transport, the spectrum is relatively broadband, with $f \lesssim \Omega_i/2\pi$, and $k \sim 1/\rho_i$. An anomalous enhancement of transport may occur for large values of $\Omega_e \tau_e$ and $\frac{\tilde{n}}{n}$.

Experimental arrangement and procecure.

We analysed the argon plasma of a hollow cathode arc (length 1.4 m, diameter .03 m). The magnetic field is varied between .05 and .4 Tesla, the plasma-current between 20A and 200 A. The electron density, n_e, and temperature, T_e, were measured with Thomson-scattering ($.2\ 10^{20} < n_e < 2.10^{20}$; $2{,}5\ \text{eV} < \hat{T}_e < 5\text{eV}$). The neutral density, n_a, is obtained from line intensities (4p - 4s transition 696.5 nm) and a collisional radiative model of the Ar I-system [5]. Ion- and neutral temperatures follow from the Doppler broadening of Ar II and Ar I lines. For the experimental determination of the ion transport we need the source term S_i. As the axial gradients are weak and the axial component of the ion systematic velocity w_{zi} is small (though nonzero [6]) we may write from the ion mass balance (recombination can be neglected):

$$nw_{ri}^{exp} = \frac{1}{r}\int_o^r r\ S_i(r)dr = \frac{1}{r}\int_o^r n_e n_a \langle\sigma v_e\rangle_{ion}$$

Results and discussion.

In fig. 2 the measured diffusion coefficient D^{exp} is compared with classical transport, D^{Cl} as a function of the Hall parameter, $\Omega_e \tau_e$. The measurements refer to the plasma near the axis at a location halfway the electrodes. It is observed that for several conditions the diffusion is remarkably reduced as compared to classical transport. We conclude, that for these conditions rotation with ion-friction improves plasma confinement appreciably. However, for large values of $\Omega_e \tau_e$ (and increasing values of the fluctuation level) the improvement deteriorates contrary to the expectations based on the rotational reduction only. The fluctuation levels are typically between $<10^{-3}$ (for low values of $\Omega_e \tau_e$) up to $>10^{-2}$ (for larger values of $\Omega_e \tau_e$). We observe indeed an anomalous diffusion with values which are in agreement with the expectations. We may conclude that anomalous transport takes over for large values of $(\Omega_e \tau_e)\ \frac{\tilde{n}}{n}$.

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