Experimental study of particles and heat transport in T-10 Ohmic plasmas

<u>N.Timchenko</u>, V.Vershkov, V.Karakcheev, S. Krasnjanskii, V. Krupin, D.Shelukhin,
V.Merejkin, D.Sarichev, A.Gorshkov, I. Belbas

Insitute of Nuclear Fusion, RRC "Kurchatov Institute", Moscow, Russia.

Experimental study of heat and particles transport with simultaneous turbulence measurements is important for understanding physical mechanisms determine transport in tokamak. In the present experiments the dependence of transport on density is investigated. The dependence of energy confinement on density in OH plasmas had being one of the main topics of experiments for more than 25 years. The present investigation is complemented by impurity transport study, heat transport calculations and turbulence measurements. Due to the lithium gettering discharges with low Z_{eff} and low recycling had been obtained that gave possibilities to wide a range of achieved plasma densities in the experiments for both low and high values. Advanced diagnostic facilities including measurements of ion and electron temperature profiles, electron density profiles, radiation power, Z_{eff} provided new possibilities to study heat transport by power-balance analysis through both electron and ion channels. Particle transport has been studied using impurity ions.

Experimental data

A set of experiments with a line averaged plasma densities varying in the region of $0.4<n<5.6*10^{19} m^{-3}$ has been carried out in Ohmic plasmas. Shorts parameters are $I_p=200kA$, $B_T=2.4T$, $R/a = 1.5m/0.3m$. In the same density range a gas-puff of impurities with different mass and ion charge (Ar and He) was carried out in a stationary phase of OH discharges. X-ray crystal monochromator RM-2 was used for registration of argon ions line radiation. Turbulence measurements were performed by means of the correlation reflectometer. Other experimental data were obtained from the following diagnostics: electron density profiles from a combination of two interferometers: an HF interferometer ($\lambda = 0.9$ mm) and an HCN laser interferometer ($\lambda = 337\mu$m); electron temperature T_e from ECE and SXR (PHA)
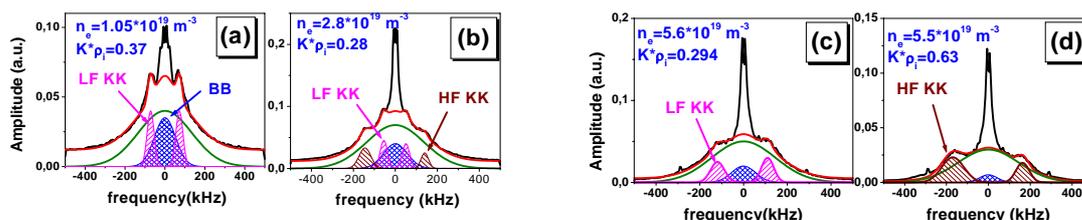

Figure 1. Fourier spectra of reflectometer signals at ρ~0.5: low density(a); intermediate density (b); high density –the regime with high gas influx (c) and the regime with low gas influx (d).

diagnostics; ion temperature measurements have been performed by means of active CXRS (CX) diagnostics, passive neutral analyzer and due to neutron flux measurements. Z_{eff} was obtained from bremsstruhlung in a visible region. Radiation losses were measured by AXUV-detectors and bolometers. Energy confinement was calculated using diamagnetic measurements.

Experimental and simulation results

In Fig.1-Fig.4 the results of measurements of turbulence, impurities confinement, central ion and electron temperatures are presented. The turbulence measurements (Fig.1) have shown that type of dominant mode changes on the density scan. At low density low frequency quasi coherent (ITG) is a dominant mode (fig.1a). Intermediate densities are characterized by the presence of both ITG and high frequency quasi coherent (TEM) modes (Fig.1b). At high densities two regimes differ in confinement were obtained. In the case of high gas influx the degradation of confinement is observed and ITG mode was found to dominate (Fig.1c). After gas influx decrease the improvement in confinement is observed. ITG mode is stabilized in the presence of increased density gradient and TEM mode becomes dominant (Fig.1d) [1].
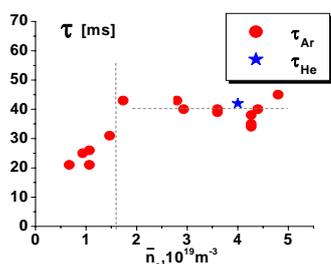

Figure 2. Ar confinement times versus line averaged density.

Argon confinement times, τ_{Ar}. are plotted in Fig.2. Argon confinement times have been obtained from evolution of Ar^{+16} line radiation in steady-state discharges after short gas puff. As seen from Fig.2 τ_{Ar} does not depend on density in a wide range of intermediate densities and decreases strongly at low density. Confinement of He impurity plotted in the same figure is found to be close to that of argon. A similar result was obtained earlier in Alcator A and C [2].

Central ion, $T_i(0)$, and electron, $T_e(0)$, temperatures are plotted in fig.3.and Fig.4 Good agreement of $T_i(0)$ with values of "Artsimovich" neoclassical formula predictions is seen at the intermediate densities. $T_e(0)$ decreases with increase in density, while $T_i(0)$ does not depend on density within the experimental uncertainty at intermediate densities and drastically decreases at low densities. It should be noted that at low densities the presence of significant fraction of non thermal electrons as well as non thermal ions are observed. At high densities in the case of high gas influx the degradation of confinement is found and ion temperature decreases. At low gas influx the transition to the regime of improved confinement takes place and increase of both the ion and the electron temperatures occurs.
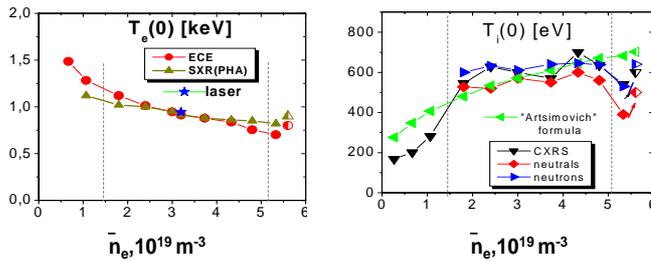
Figure 3. Central ion temperature versus line averaged density

Figure 4. Central electron temperature versus line averaged density

Heat transport calculations have been performed in steady state condition by power-balance analyses using ASTRA code. In OH discharges the ratio of the ion to the electron heat fluxes is found to vary significantly with the density scan. As seen in Fig.4 heat transport channel through electrons dominates at low densities, whereas at high densities heat transport throw ion channel strongly dominates. Electron thermal diffusivity, χ_e, and ion thermal diffusivity, χ_i, calculated at a mid-radius, are plotted in Fig.4b and Fig.4b as a function of density. Being anomalous in the whole density range, χ_e and χ_i exhibit quite different behavior depending on plasma density. The electron thermal diffusivity is a monotonically decreasing function of density, while χ_i is independent on density in the wide region of intermediate densities. At high densities two regimes –with increased and strongly decreased χ_i correspond to the cases of degraded and improved confinement.

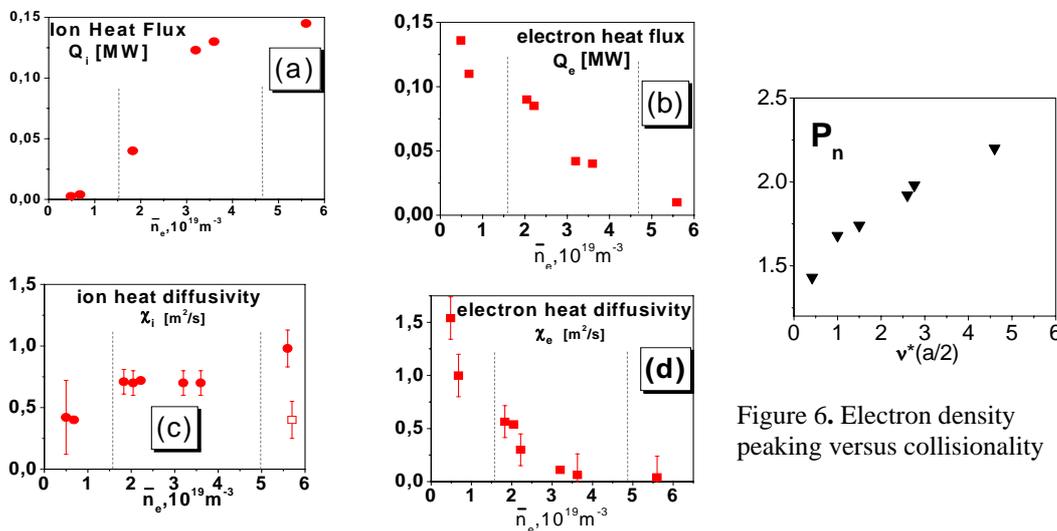Figure 6. Electron density peaking versus collisionality

Figure 5. (a) Ion heat fluxes, (b) electron heat fluxes, (c) ion heat diffusivity and (d) electron heat diffusivity versus line averaged density.

For the density range of $0.4 < n_e < 5*10^{19} m^{-3}$ the dependence of the density peaking $P_n = n_e(0.4)/n_e(0.8)$ on collisionality, $\nu^* = 0.1*R*n_e*Z_{eff}/T_e^2$, is shown in Fig.6. It is seen that P_n is an increasing function of collisionality in OH discharges under consideration.
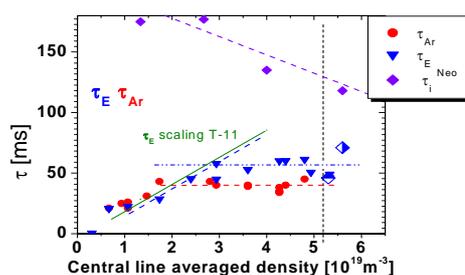
Figure 7. Energy confinement time, t_E, and confinement times of argon ions versus line averaged plasma density. The lines are visual guides.

Fig.7 shows energy confinement time, τ_E, versus line averaged plasma density. Confinement times of Ar^{+16} ions are plotted for comparison. It is seen that both linear and "saturated" confinement Ohmic regimes are presented. As the electron heat flux is found to dominate at low densities the linear regime on confinement is corroborated by the decreasing function of χ_e on density in this region. After transition to the intermediate and the high densities regimes the ion heat flux becomes dominant and independency of χ_i on density is consistent with "saturated" regime. In the "saturated" regime confinement times of energy and argon ions demonstrate similar behavior and $\tau_{Ar} \sim 0.6\tau_E$. At low density $\tau_{Ar} \sim \tau_E$.

Summary

Scan on density has shown that in Ohmic plasmas the regimes varying in dominated heat channels and type of turbulence are obtained. In a wide working region of intermediate densities, $1 < n_e < 5 *10^{19}$ m^{-3}, significant variation in parameters such as the ratios of Q_e/Q_i , T_e/T_i, amplitudes of ITG/TEM modes is found. At the same time similar behavior of the ion heat and impurity ions transport is observed in this region and both χ_i and τ_{Ar} are independent on density. χ_e decreases with the electron density increase, which is in coincidence with T-11 scaling [3]. At low density, whereas the electron heat flux dominates, ITG is a dominant mode. Increased argon ions and ion heat transport compared to the intermediate region on density is found. The presence of a noticeable fraction of non thermal electrons and ions observed in this region can affect the transport. At high density the ion heat flux is found to dominate. Transition to the regime of improved confinement takes place in the presence of the density gradient increasing and stabilization of ITG mode that is consistent with theory predictions [4]. Increase of the density peaking with collisionality is corroborated by inward directed pinch velocity and the expectations for dependency on parameters of thermo-diffusion mechanism in the case of ITG driven mode [4].

References
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