Study of the Isotopic Effect on Ohmic L- and H-mode Confinement on Globus-M

N.V. Sakharov 1), A.A. Berezutskiy1), F.V. Chernyshev 1), V.K. Gusev 1),
A.D. Iblyaminova2), N.A. Khromov 1), G.S. Kurskiev 1), A.D. Melnik 1), V.B. Minaev 1),
A.N. Novokhatsky 1), M.I. Patrov 1), Yu.V. Petrov 1), S.Yu. Tolstyakov 1), F.Wagner3),
E.G. Zhilin 4)

1) *Ioffe Physical-Technical Institute, St. Petersburg, Russia*
2) *St. Petersburg State Polytechnical University, St. Petersburg, Russia*
3) *Max-Planck-Institute for Plasma Physics, Greifswald, Germany, EURATOM Association, RLPAT St. Petersburg State Polytechnical University*
4) *Ioffe Fusion Technology Ltd., St. Petersburg, Russia*

Introduction

The dependence of plasma properties on the isotope selected – hydrogen or deuterium – is a well established effect with, however, little understanding. In tokamaks there is generally an isotopic effect on confinement which is strongest under ohmic conditions [1]. With auxiliary heating, a strong isotopic effect is observed in the power threshold into the H-mode: P_{thr}~A_i^{-1} [2]. No isotopic effect has been reported from stellarators [3]. Not much is known about the isotopic effect in spherical tokamaks. Here we report on the isotopic effect on ohmic discharges of the spherical tokamak Globus-M (plasma major radius $R \approx 0.33$-0.36 m, plasma aspect ratio $R/a \approx 1.5$-1.6, toroidal magnetic field is 0.4 T). Because of the high ohmic power in STs, the plasma frequently transited into the H-mode. Therefore, we discriminate between L- and H-mode ohmic confinement. The isotope study has been carried out under carefully controlled wall conditions. Graphite of RGTi-91 grade is used as the basic material for the first wall protection in Globus-M. This material has low porosity and sputtering coefficients. More than 600 tiles cover up to 90% of the plasma facing surface. All graphite tiles were cleaned mechanically and then washed in an ultrasonic bath and baked at 400^0C in vacuum. This treatment yielded strongly improved plasma parameters allowing experiments at higher plasma volume and higher current.

Experiment

The experiments have been started in hydrogen plasmas. Hydrogen was puffed in from the low magnetic field side. Two valves were used for deuterium puffing from the high and low magnetic field side, which did, however, not make a difference. The plasma isotope composition as well as the ion temperature was measured by the neutral particle analyzer ACORD-12 [4]. After the experiments in hydrogen the vacuum vessel was baked at a temperature of 200^0C. The plasma facing surface was cleaned with glow discharge in helium. The measured percentage of hydrogen in deuterium plasmas $n_H/(n_H + n_D)$ did not exceed 10%. Each experimental session was also preceded by glow discharge cleaning during 5-8 hours. The density scan in hydrogen and deuterium plasmas was performed generally in lower single-null configuration at a plasma current 0.175-0.2 MA and a safety factor $q_{95} \sim 4.5$-5.5. The plasma average density was measured by 0.8 mm interferometer along a vertical chord at R=0.42 m close to the plasma magnetic axis. The plasma stored energy was determined by EFIT magnetic equilibrium reconstruction [5] and from kinetic measurements processed by the ASTRA code [6].

Results and discussion

Fig. 1 compares the energy confinement time τ_E as a function of the line-averaged plasma density for hydrogen and deuterium plasmas. The estimated gas puffing rate was approximately 30% larger for the case of deuterium puffing. This does not indicate an improvement in particle confinement as usually observed.

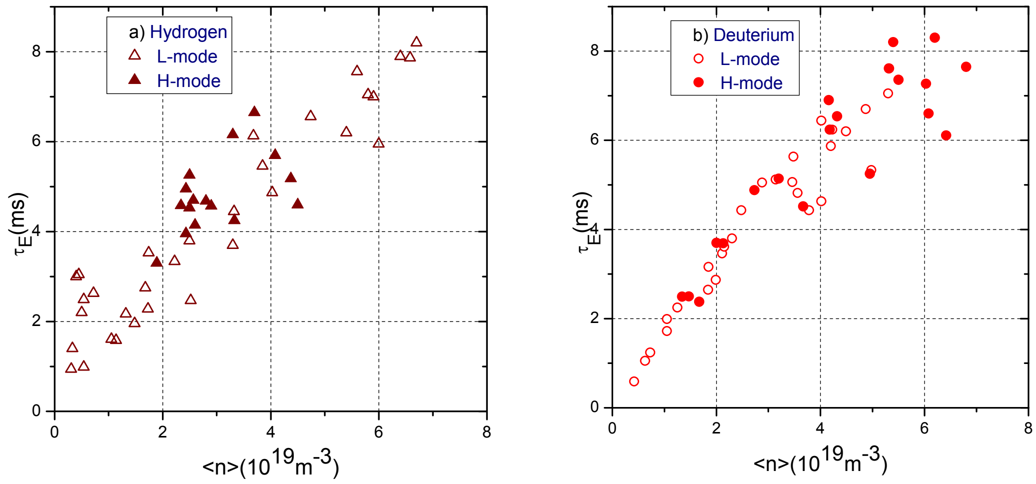

Fig.1 Energy confinement time as a function of density in hydrogen (a) and deuterium (b) plasma.

In both cases τ_E is observed to vary linearly with n_e with some tendency of saturation toward higher densities. L- and H-mode plasmas are discriminated in Fig. 1. The maximum densities are by a factor of 1,5÷2 below the Greenwald limit. Absolute τ_E values are approximately the same for hydrogen and deuterium plasmas. The L-H transition did not affect significantly the energy confinement time. In hydrogen plasmas the H-mode transition was observed in a rather narrow density range. Unexpectedly for hydrogen, a spontaneous density rise resulted in H-mode termination. In deuterium plasmas the H-mode existed in a larger density range. In most shots L-H transitions were accompanied by ELMs synchronized with sawtooth oscillations.

Measured τ_E values in Fig.1 are consistent with Alcator scaling for ohmically heated plasmas: $\tau_E = 0.07\times n_e a R^2 q$ (where τ_E – s; n_e – 10^{20}m^{-3}; a,R – m) with $q = q_{95}$. The nearly linear density dependence of the energy confinement time in a wide density range ($n_e \sim (2\div7)\times10^{19}$ m^{-3}) is in accordance with kinetic measurements.

Fig.2 demonstrates the core electron temperature measured by TS diagnostic. In Fig.2 and in subsequent figures the experimental points are combined for L and H-modes. In the experimental density range the average variation of the electron temperature $\Delta T_e \sim 100\div150$ eV is small.

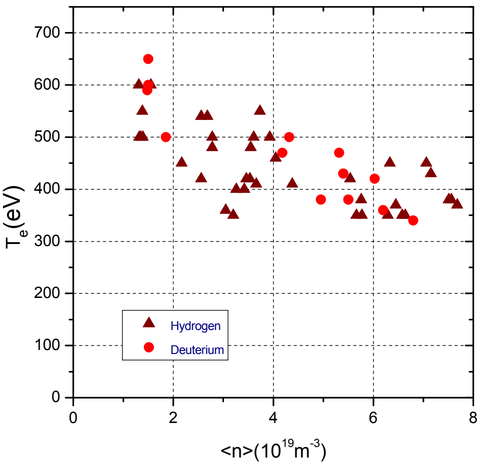

Fig.2. Central electron temperature as a function of density.

At high density, the measured ion temperature, has to be corrected due to plasma opacity. $T_i \sim$ 250-300 eV for $n_e \sim 6\times10^{19}$ m^{-3}. For modeling the discharges, electron temperature and density profiles measured by the multipulse TS diagnostic and the measured core ion temperature were used as the input parameters. The experimental plasma voltage was used as a fitting parameter. Typical T_e profiles at a line-averaged density $n_e \approx 7\times10^{19}$ m^{-3} are shown in Fig.3. The radial electron temperature distributions are approximately the same in hydrogen and deuterium plasma. The electron thermal diffusivity χ_e~6 m^2/s calculated near the radius r ~ a/2 is – as expected – clearly above the neoclassical value $\chi_e^{neo} \sim 0.1$ m^2/s as determined by the NCLAS code [7]. Modeling also confirms the measured ion temperature on the basis of neoclassical ion heat transport coefficients. This aspect - the ions remain neoclassical - may be the reason that no saturation in τ_E is observed. Ion collisionality $\nu_i^* \approx 0.4$ for $n_e(0) \sim 7.8$ m^{-3} and $T_i \approx 215$ eV. The calculated kinetic values of the plasma stored energy are in accordance with the results of magnetic equilibrium reconstruction as plotted in Fig.1.

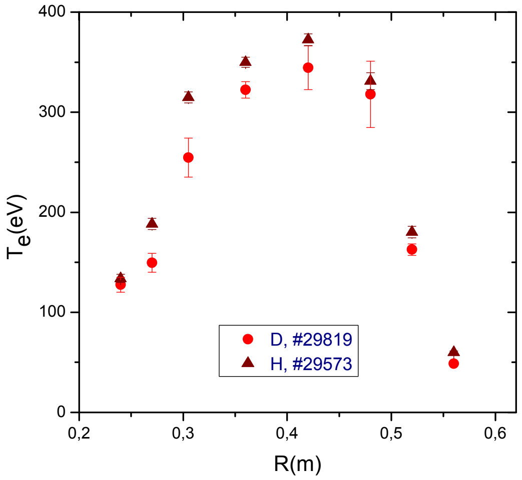

Fig.3. Electron temperature profiles in hydrogen and deuterium plasma

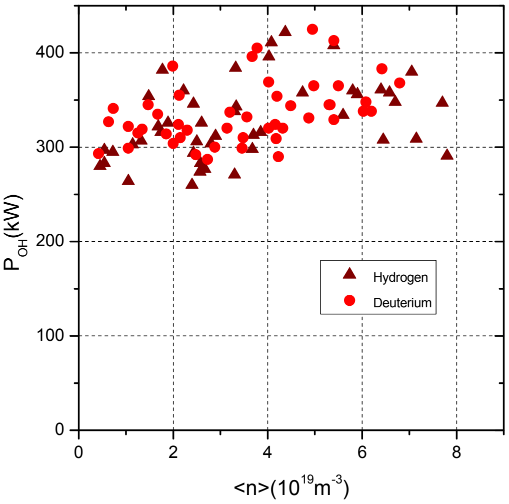

Fig.4. Ohmic heating power as a function of density.

The ohmic heating power versus density is shown in Fig.4. There is little or no systematic dependence of P_{OH} on density. The heating power is sustained near the average value ~ 350 kW despite 20-25% decrease of the electron temperature. The reason can be an appreciable bootstrap current at beta poloidal of $\beta_p \sim 0.5 \div 0.7$ as obtained at high density. According to ASTRA simulation the bootstrap current fraction $I_{bs}/I_p \sim 10 \div 15\%$. Also a decrease of Z_{eff} with density can cause a rather constant Ohmic power.

Radiation losses (Fig.5) are higher in deuterium plasmas possibly caused by stronger wall sputtering. However, the estimated fraction of radiation losses after graphite tiles cleaning does not exceed $P_{rad}/P_{OH} \le 10\%$. Therefore, this low value does not affect significantly the energy balance.

Nothing can be said at present about an isotopic dependence of the H-mode power threshold. Fig. 1 indicates that there is no H-mode development at lower density. Whether the slight difference in the lower density limit between H and D is caused by a difference in P_{thr} and indicates the usually observed isotopic effect has to be seen.

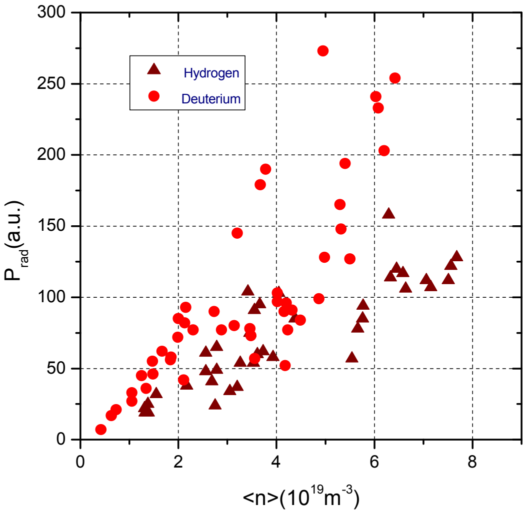

Fig.5 Radiation power as a function of density.

The work is supported by RF Ministry of Education and Science contr. No. 11.G34.31.004; No. 16.518.11.7003; No. 16.552.11.7002 and by the RFBR grant 10-02-00746.

References.

[1] M. Bessenroth-Weberpals, et al. Nucl. Fusion **33** (1993) p.1205

[2] E. Righi, et al. Nucl. Fusion 39 (1999) p. 309

[3] M. Hirsch, et al. Plasma Phys. Control. Fusion **50** (2008) 053001

[4] A.B.Izvozchikov, et al. // Technical Physics, 1992, vol. 37, p. 201

[5] L.L.Lao et al, Nucl. Fusion, **25**, N11 (1985) p.1611

[6] Pereverzev, G., Yushmanov, P.N., Max-Planck IPP report 5/98 (2002)

[7] Houlberg W.A. et al, Phys. Plasmas. 1997. V. 4. P. 3230