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Isotope effect in turbulent transport in high density FT-2 tokamak discharges

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MOTIVATION

Strong isotope effect was found in energy transport: significant difference in energy confinement for **hydrogen** (H) and **deuterium** (D) ohmic plasmas at **high densities** $<n_e> \sim (6\text{-}9)\cdot10^{19}$ m^{-3}.

3 scenarios to study isotope discrepancy both in energy transport analysis and turbulence:

- Ohmically heated (OH) discharges, H-mode in deuterium, L-mode in hydrogen;
- Fast current ramp up (CRU) discharges;
- Lower hybrid heating (LHH) scenario.

Detailed comparative study is possible due to the opportunity of direct turbulence and plasma velocity **measurements** performed with Langmuir probes and microwave diagnostics as well as global energy transport analysis.

Experimental/modeling approach

- FT-2 tokamak: *a* = 0.08 m, *R* = 0.55m, $I_{pl} \sim$ 32-35 kA, $B_T \sim$ 2.2 T, $q_{95} \sim$ 3-3.5
- all presented results are taken from typical Ohmic discharges,
- **two** working gases were used: ***hydrogen** and **deuterium,***
- ASTRA code transport modeling based on the experimental data,
- τ_E calculation with ASTRA code, based on **measured** profiles of T_e, T_i, n_e

$$\tau_E = W_{tot}/(Q_{OH} - dW_{tot}/dt)$$

Basic diagnostics:

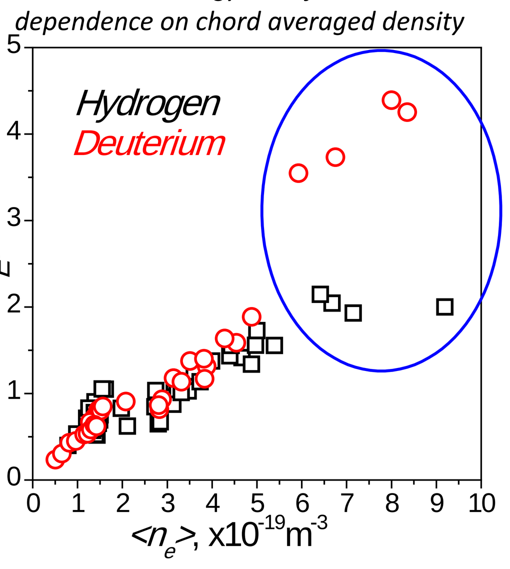
T_e, n_e – thomson scattering, full profile,
T_i – charge exchange, r: 0-4 cm,
n_e – interferometer, full profile.
P_{rad} – bolometer, full profile.

***Turbulence** measurements:*

- 5-electrode Langmuir probe,
- reflectometry,
- enhanced scattering

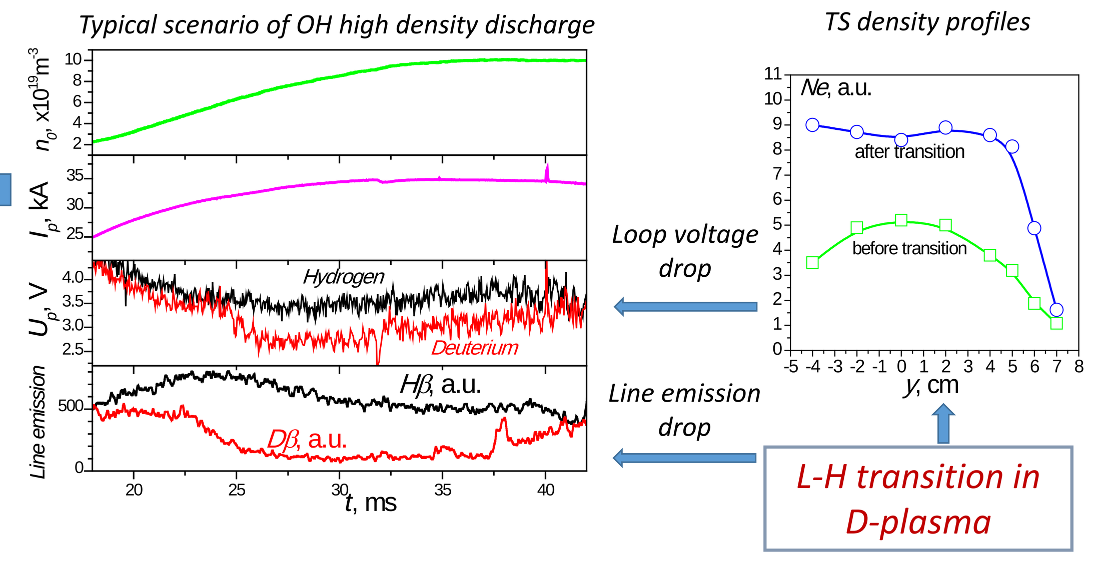
OH high density discharges. Spontaneous transition to H-mode in deuterium vs stable L-mode in hydrogen

The total energy confinement time dependence on chord averaged density



Isotope effect in energy confinement

Typical scenario of OH high density discharge / *TS density profiles*

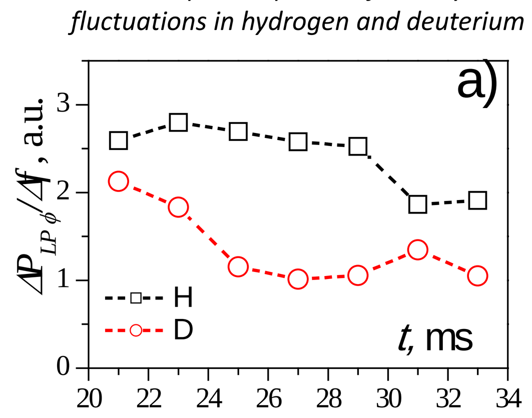


Langmuir probe measurements

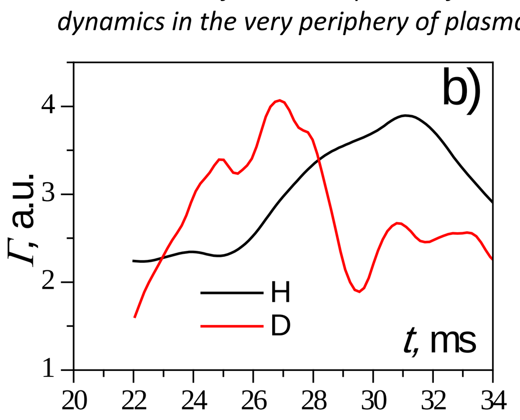
D-plasma: drop of the spectral density of fluctuations of the floating potential and radial fluctuation particle flux near LCFS

Turbulence suppression

The spectral power of density fluctuations in hydrogen and deuterium



The radial fluctuation particle flux dynamics in the very periphery of plasma.



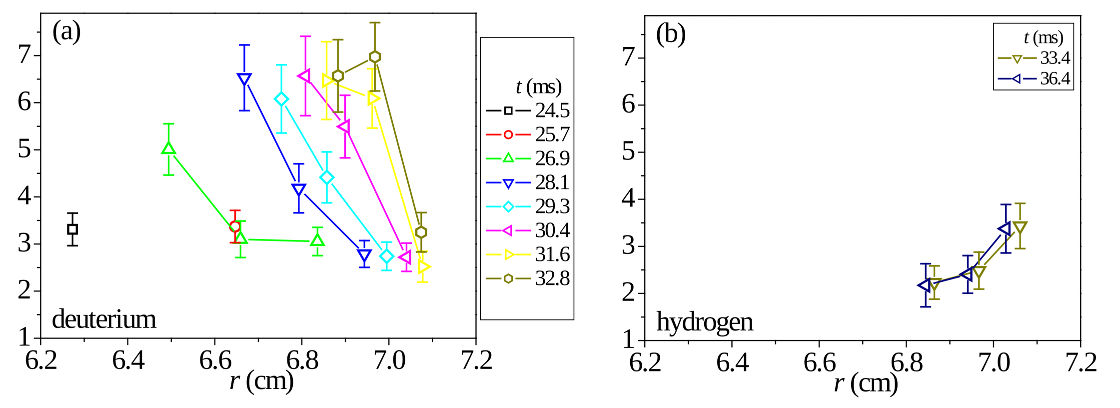
Doppler enhanced scattering measurements

D-plasma: growth of the poloidal rotation velocity during L-H transition on plasma periphery

Growth of the shear of the poloidal rotation ω_{ExB} from 0.6 to 1.8 MHz

Turbulence suppression

Radial profiles of the poloidal plasma velocity, measured by Doppler enhanced scattering in the ohmic regime with increasing density



CONCLUSIONS

3 experimental series in hydrogen and deuterium **high density** plasma are performed at the FT-2 tokamak:

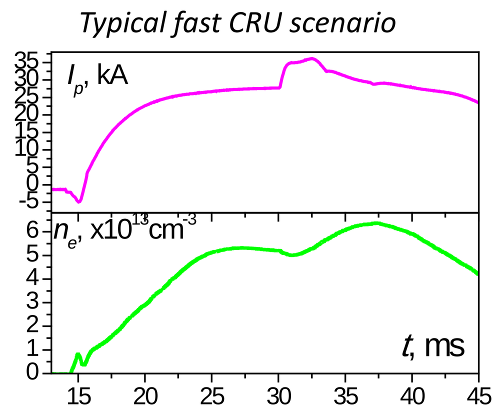
1.OH scenario demonstrates strong isotope effect in global confinement. Total energy confinement time value in deuterium twice as higher than in hydrogen. Features of transition to H-mode in deuterium, confirmed by direct measurements of turbulence at plasma periphery and strong plasma rotation shear growth. Stable L-mode in hydrogen.

2.Fast CRU scenario: the attempt to initiate L-H transition by current ramp up failed in spite of appreciable improvement of energy confinement at the current relaxation stage of discharge both in hydrogen and deuterium plasma. The level of small-scale turbulence at the plasma periphery demonstrates a factor of 10 higher values for deuterium (comparing with hydrogen) at the current relaxation stage.

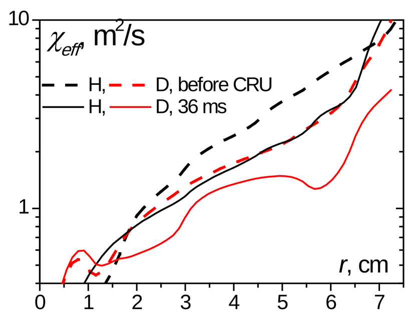
3.LHH scenario: demonstrated the stability and robustness of both H-mode in deuterium and L-mode in hydrogen. Significant increase of ion temperature (a factor of 1.5) due to central RF heating in deuterium caused no changes on global confinement after switching of RF power. Peripheral application of RF power in hydrogen could not change somehow stable L-mode, presenting the same values of τ_E before and after LH pulse. Microwave measurements at plasma periphery show the significant growth of shear ω_{ExB} values in deuterium during LHH up to the level of 2-3 MHz, allowing suppression of wide range of possible turbulent modes in plasma. At the same time H-plasma presents much smaller ω_{ExB} values before and after LH pulse.

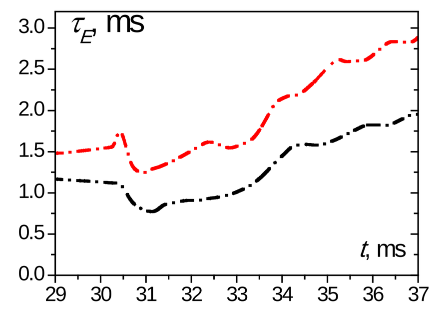
CRU: Fast current ramp up experiments

Typical fast CRU scenario



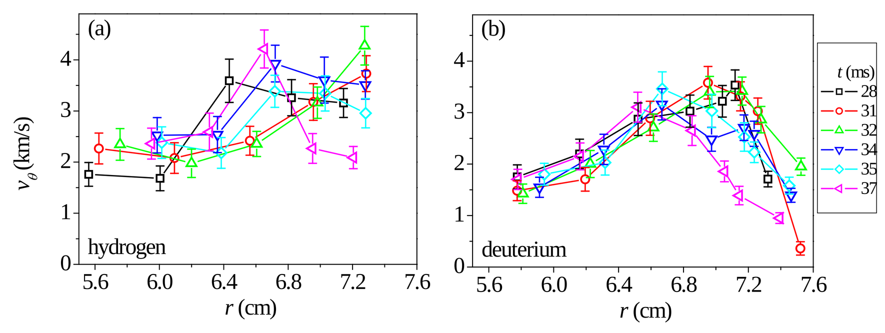
Dynamics during CRU in hydrogen (black) and deuterium (red) of effective electron thermal conductivity and total energy confinement time



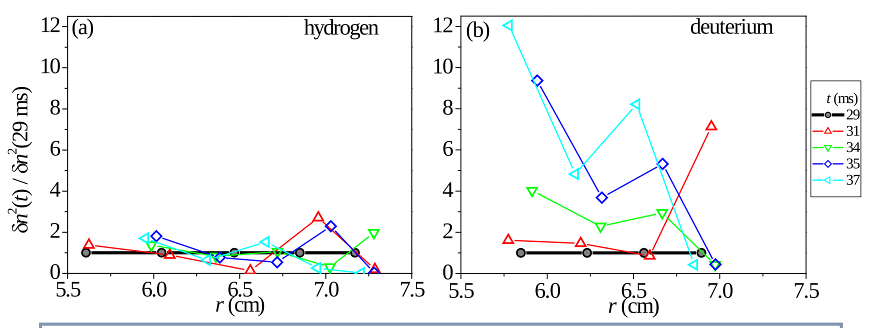


τ_E increases 1.5 -2 times on current relaxation stage both in H- and D- plasma

Radial profiles of the poloidal plasma velocity measured by Doppler enhanced scattering in the regime with CRU

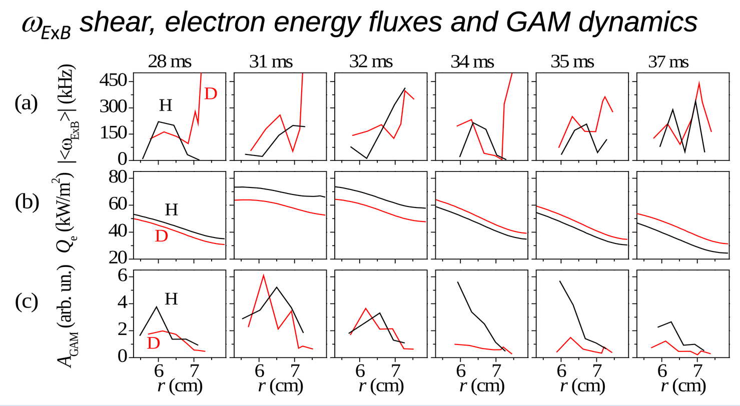


Radial profiles of the relative change in the level of small-scale turbulence



The level of small-scale turbulence measured at the plasma periphery in the hydrogen discharges remained at the same level as before the CRU, while in deuterium it increased by a factor of 2-10

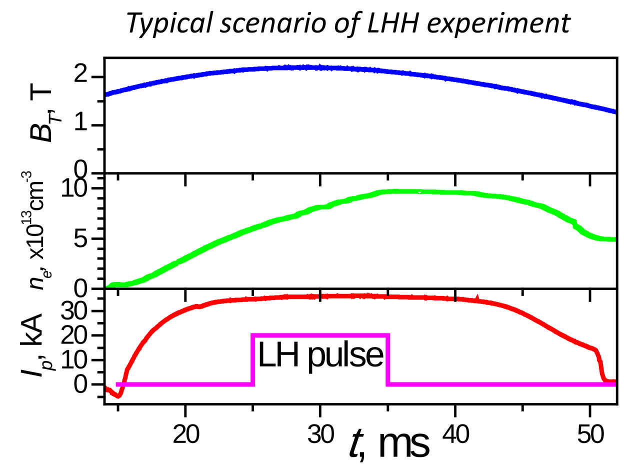
ω_{ExB} shear, electron energy fluxes and GAM dynamics



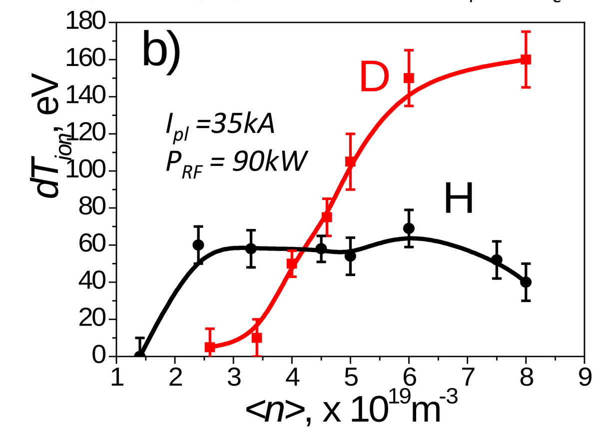
red for deuterium, black for hydrogen: (a) The mean value of the poloidal rotation shear (b) Electron energy fluxes (c) GAMs amplitude

LHH: lower hybrid heating experiments

Typical scenario of LHH experiment

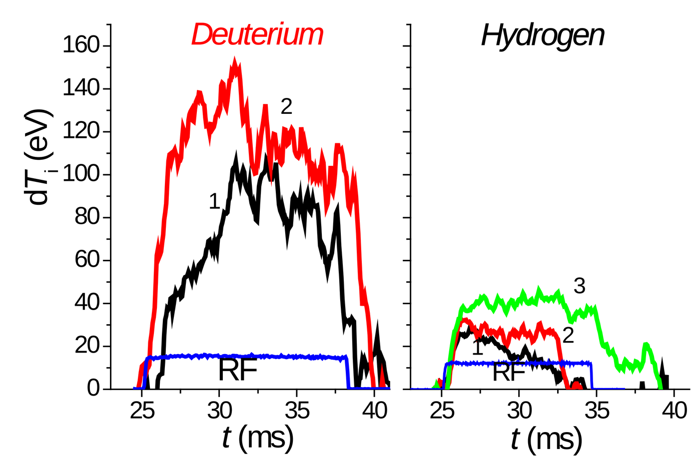


Dependency of the increment dT_i on $<n_e>$

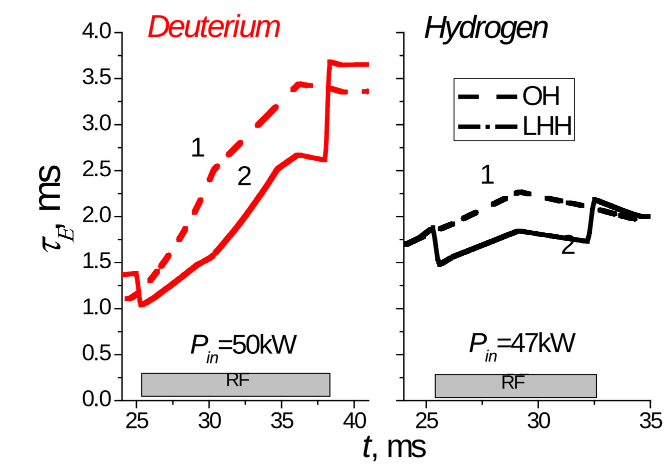


In H-plasma increment dT_i does not depend on plasma density, In D-plasma it grows and saturates at high densities

Increments of the central ion temperature dT_i dynamics at different input RF power



Evolution of τ_E in the scenarios with LHH (solid lines) versus comparable OH high density discharges (dash lines)



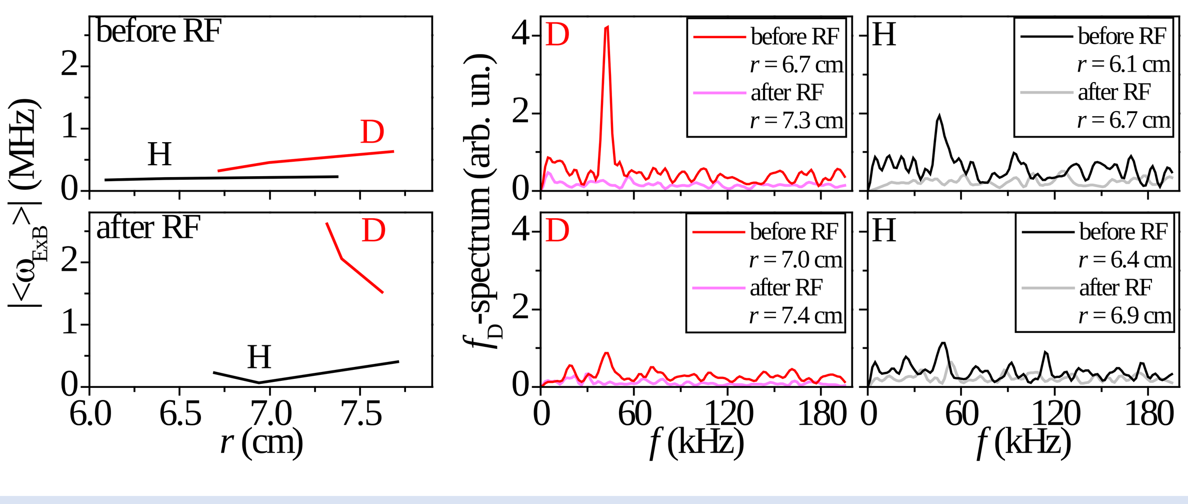
After switching off the RF power both for H- and D-plasma the confinement returns to the same level as it would be without LHH

The mean value of the poloidal rotation shear, measured before and after the RF pulse (red for deuterium, black for hydrogen) and GAMs spectra.

D-plasma: after LH pulse: growth of the shear of the poloidal rotation ω_{ExB} from ~0.6 to ~2-2.5 MHz

decrease in the fluctuation level

H-plasma: ω_{ExB} remains on low level



REFERENCES

[1] MAGGI, C., et al., 2018 Plasma Phys. Control. Fusion 60 014045
[2] NISKALA, P., et al., 2018 Nuclear Fusion 58, 112006.
[3] KOUPRIENKO, D., et al., 45th EPS Conference on Plasma Physics, P4.1097 (2018)
[4] PEREVERZEV, G. AND YUSHMANOV, P., Report No. 5/98. (Max-Planck-Institut für Plasmaphysik, Garching, 1998)
[5] ALTUKHOV, A., GURCHENKO, A., GUSAKOV, E. et al., PPCF **58** (2016) 105004
[6] GURCHENKO, A., GUSAKOV, E., ALTUKHOV, A., et al., Nucl. Fusion **47** (2007) 245
[7] GURCHENKO, A., GUSAKOV, E., ALTUKHOV, A., et al., PPCF **55** (2013) 085017
[8] BELOKUROV, A., et al., 2020 Phys. Scr. 95 115604
[9] LEVITSKII, A., SAKHAROV, I., SHATALIN, S., Prib. Tekh. Eksp., No. 5, 153 (1992).
[10] GURCHENKO, A., et al., 35th EPS Conference on Plasma Physics, O4.046 (2008)
[11] LASHKUL, S., et al. Plasma Physics Reports, 2020, Vol. 46, No. 9, pp. 863–873.

ACKNOWLEDGEMENTS

The financial support of the Russian Science Foundation grant 17-12-01110 is acknowledged. The FT-2 tokamak maintenance was performed under financial support of the Ioffe institute state contract.