INVESTIGATION OF ISOTOPE EFFECT ON ENERGY CONFINEMENT TIME AND THERMAL TRANSPORT IN L-MODE PLASMAS ON LHD

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ABSTRACT

- Isotope effect on energy confinement time and thermal transport has been investigated for L-mode plasmas in LHD stellarator-heliotron.
- Plasmas of hydrogen(H), deuterium(D) and their mixture including helium (He) have exhibited no significant dependence on the isotope mass M in thermal energy confinement time.
- Comparison of thermal diffusivity χ/Ω_i for dimensionally similar H and D plasmas in terms of gyro-radius ρ^*, collisionality ν^* and thermal pressure β has clearly shown robust improvement in electron channel in D to compensate for unfavorable mass dependence predicted by the gyro-Bohm model.
- Characteristics of density fluctuation has been also compared among dimensionally similar plasmas.
- The transient electron heat transport does not show a substantial difference in H, D and their mixture plasmas.

BACKGROUND

- Contradiction of the Isotope mass dependence of confinement with well accepted gyro-Bohm model is a long-standing mystery in fusion research
- Deuterium experiments on LHD provide the first detailed assessment of isotope effect in stellarator-heliotron plasmas.

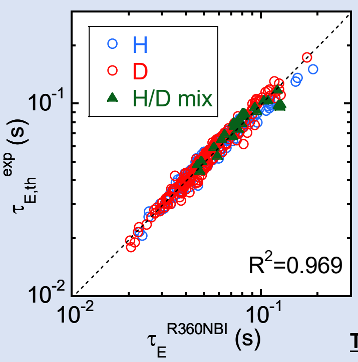
INVESTIGATED OPERATIONAL REGIMES

Condition	Ion species	N_{data}	B(T) Ave.	B(T) Min.	B(T) Max.	B(T) σ	($10^{19}m^{-3}$) Ave.	($10^{19}m^{-3}$) Min.	($10^{19}m^{-3}$) Max.	($10^{19}m^{-3}$) σ	P(MW) Ave.	P(MW) Min.	P(MW) Max.	P(MW) σ
R_{ax}=3.6m NBI	H	155	2.12	1.64	2.75	0.55	1.88	0.85	4.32	0.91	4.74	1.46	11.2	1.99
	D	200	2.33	1.38	2.75	0.57	2.29	0.84	5.71	0.93	6.00	1.41	13.0	2.45
	He	63	2.38	1.64	2.75	0.53	2.79	1.10	5.44	1.05	5.50	1.96	8.80	2.27
	H/D	21	2.75	2.75	2.75	0	2.41	1.04	3.88	0.80	5.04	3.20	8.77	1.43
	H/D/He	14	2.75	2.75	2.75	0	2.29	0.89	3.43	0.83	6.08	2.02	9.28	2.25
R_{ax}=3.6m ECH	H	63	2.75	2.75	2.75	0	2.01	0.37	4.89	1.08	1.93	1.40	3.31	0.39
	D	41	2.75	2.75	2.75	0	2.03	0.65	3.56	0.93	1.85	1.37	2.42	0.42
R_{ax}=3.75m NBI	H	180	2.11	1.57	2.64	0.54	2.43	0.82	5.59	1.00	5.57	1.04	10.8	1.94
	D	48	2.59	1.38	2.64	0.24	2.13	0.83	3.78	0.75	4.51	2.04	8.73	1.31

Note: Electron heating is predominant for most cases.

ex. for R_{ax}=3.6m/NBI statistically, P_e/P_i=3.9±2.0 hence $T_e(0)/T_i(0)$=1.79±0.37

1. Comparison of energy confinement time in experiment with the derived scaling law in the case of NBI heated plasmas with R_{ax}=3.6m



Expression by operational parameters

$$\tau_{E,th}^{R360NBI} \propto M^{-0.07\pm0.01} B^{0.85\pm0.01} \bar{n}_e^{-0.73\pm0.01} P_{abs}^{-0.81\pm0.01}$$

No significant dependence on *M*

Dimensionless expression

$$\tau_{E,th}^{R360NBI}\Omega_i \propto M^{0.94} \rho^{*-3.02} \nu^{*0.15} \beta^{-0.23}$$

Clear contribution of *M* and persistence of gyro-Bohm nature

<u>These two are robust characteristics</u>

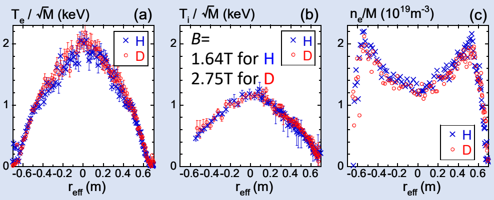
- **ECH at R_{ax}=3.6m** $\tau_{E,th}^{R360ECH} \propto M^{0.20\pm0.03} \bar{n}_e^{-0.67\pm0.02} P_{abs}^{-0.62\pm0.04}$
- **NBI at R_{ax}=3.6m including He and mix** $\tau_{E,th}^{R360all} \propto M^{-0.09\pm0.01} B^{0.88\pm0.02} \bar{n}_e^{-0.69\pm0.01} P_{abs}^{-0.82\pm0.01}$ $\tau_{E,th}^{R360all}\Omega_i \propto M^{0.89} \rho^{*-2.96} \nu^{*0.15} \beta^{-0.28}$
- **NBI at R_{ax}=3.75m** $\tau_{E,th}^{R375NBI} \propto M^{-0.04\pm0.03} B^{0.70\pm0.02} \bar{n}_e^{-0.80\pm0.01} P_{abs}^{-0.81\pm0.01}$ $\tau_{E,th}^{R375NBI}\Omega_i \propto M^{0.93} \rho^{*-2.95} \nu^{*0.18} \beta^{-0.19}$

OUTCOME

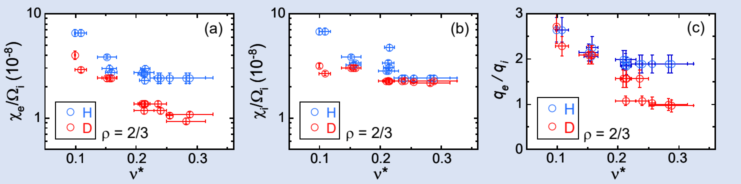
Comprehensive database arousing theoretical challenges

- Under the condition of predominant electron heating, electron loss channels behave like gyro-Bohm WITH clear mass effect (something different from gyro-radius effect)

2. Heat transport of dimensionally similar plasmas



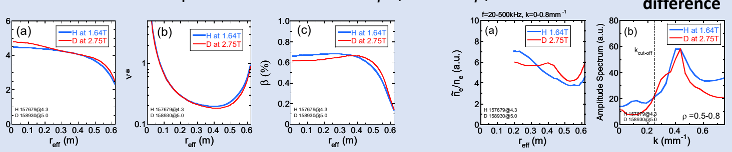
- ✓ By adjusting heating power, magnetic field and density, dimensional similar plasmas in terms of ρ^*, ν^* and β can be obtained
- ✓ Dimensionless heat diffusivity χ_e/Ω_i is improved robustly.
- ✓ This implies $\chi_e/\Omega_i \propto 1/M$ consistent with $\tau_E\Omega_i \propto M$



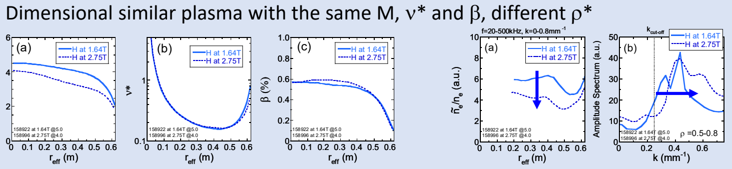
3. Density fluctuation by PCI in comparison of dimensionally similar plasmas

✓ Dimensional similar plasma with the same ρ^*, ν^* and β, different *M*

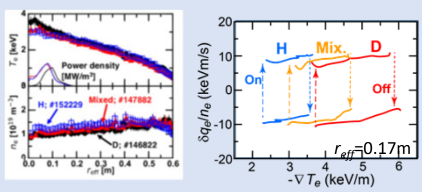
No significant difference



✓ Dimensional similar plasma with the same M, ν^* and β, different ρ^*



4. Hysteresis in transient response in ECH plasmas



- ✓ Modulated ECH (1MW/23Hz) is applied to steady NBI (3.6MW) plasmas
- ✓ The trajectories clearly shows the hysteresis loop with the leap when the MECH is turned on and off.
- ✓ The hysteresis widths are the same for plasmas of H, D and their mixture, which indicates that the turbulent diffusion coefficient does not change by the isotope. This fact is consistent with no significant dependence on *M* in τ_E and χ

CONCLUSION

- Detailed study of isotope effect on confinement in LHD has shown that no significant difference in H and D from the operational viewpoint, however, more important message is that gyro-Bohm nature and clear mass effect besides gyro-radius co-exists.
- The key challenge is to clarify the underlying physics of the identified mass effect besides gyro-radius.
- The observations shown in this study have shown distinction to tokamaks and rouse key challenges to common physics picture of isotope effect in toroidal plasmas.

ACKNOWLEDGEMENTS / REFERENCES

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