Isotope dependence of energy, momentum and particle confinement in tokamaks

H. Weisen,C.F.Maggi, M. Oberparleiter, F. J. Casson, Y. Camenen. S. Menmuir, L.Horvath, F.Auriemma,T.W.Bache, N. Bonanomi, A. Chankin,E.Delabie, L. Frassinetti, J. Garcia, C.Giroud, D.King, R. Lorenzini, M.Marin, P.A.Schneider, P.Siren, J.Varje, E. Viezzer and JET contributors

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Abstract:

The isotope dependence of plasma transport will have a significant impact on the performance of future D-T experiments in JET and ITER and eventually on the fusion gain and economics of future reactors. In preparation for future D-T operation on JET, dedicated experiments and comprehensive transport analyses were performed in H, D and H-D mixed plasmas. The analysis of the data has demonstrated an unexpectedly strong and favourable dependence of the global confinement of energy, momentum and particles in ELMy H-mode plasmas on the atomic mass of the main ion species, the energy confinement time scaling as $\tau_E \sim A^{0.5}$ (Maggi et al., Plasma Phys. Control. Fusion, vol. 60, 2018, 014045; JET Team, Nucl. Fusion, vol. 39, 1999, pp. 1227–1244), i.e. opposite to the expectations based only on local gyro-Bohm (GB) scaling, $\tau_E \sim A^{-0.5}$, and stronger than in the commonly used H-mode scaling for the energy confinement (Saibene et al., Nucl. Fusion, vol. 39, 1999, 1133; ITER Physics Basis, Nucl. Fusion, vol. 39, 1999, 2175). The scaling of momentum transport and particle confinement with isotope mass is very similar to that of energy transport. Nonlinear local GENE gyrokinetic analysis shows that the observed anti-GB heat flux is accounted for if collisions, E × B shear and plasma dilution with low-Z impurities (9Be) are included in the analysis (E and B are, respectively the electric and magnetic fields). For L-mode plasmas a weaker positive isotope scaling $\tau_E \sim A^{0.14}$ has been found in JET (Maggi et al., Plasma Phys. Control. Fusion, vol. 60, 2018, 014045), similar to ITER97-L scaling (Kaye et al., Nucl. Fusion, vol. 37, 1997, 1303). Flux-driven quasi-linear gyrofluid calculations using JETTO-TGLF in L-mode show that local GB scaling is not followed when stiff transport (as is generally the case for ion temperature gradient modes) is combined with an imposed boundary condition taken from the experiment, in this case predicting no isotope dependence. A dimensionless identity plasma pair in hydrogen and deuterium L-mode plasmas has demonstrated scale invariance, confirming that core transport physics is governed, as expected, by the 4 dimensionless parameters ρ*, ν*, β, q (normalised ion Larmor radius, collisionality, plasma pressure and safety factor) consistently with global quasi-linear gyrokinetic TGLF calculations (Maggi et al., Nucl. Fusion, vol. 59, 2019, 076028). We compare findings in JET with those in different devices and discuss the possible reasons for the different isotope scalings reported from different devices. The diversity of observations suggests that the differences may result not only from differences affecting the core, e.g. heating schemes, but are to a large part due to differences in device-specific edge and wall conditions, pointing to the importance of better understanding and controlling pedestal and edge processes.