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Scientific progress in tokamak physics with different main ions

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In fusion plasmas energy needs to be confined in a way to reach temperatures in the core high enough for nuclear fusion while maintaining a cold edge to be compatible with material limits. The required gradients in the system drive a strong outward transport.

To investigate the transport properties high temperature plasmas can be performed with the different hydrogen isotopes - hydrogen/protium H, deuterium D and tritium T - or helium He as main ions.

In ASDEX Upgrade experiments have been conducted with H, D and He, and in JET with H, D and T, which includes the results of the latest T campaign at JET. These experiments show a complex system of interacting transport channels and mechanisms linking the core and edge of the plasma. Assuming the system is not fundamentally altered when changing the isotope mass, we obtain a more complete picture when changing the mass from H to D to T, as this breaks co-linearities which can be present for experiments with a single isotope.

In particular, the steady state heat balance between the different transport channels is modified by changing the isotope mass and therefore, the electron-ion equipartition. This allowed us to explain the isotope mass dependence in electron heated Ohmic and L-mode plasmas [1-2].

In H-mode the coupling between core and pedestal can be overcome due to the different mass dependence of the transport in those regions. For the first time an experimental separation of both regions was achieved for plasmas with different isotopes. While the plasma core shows only small differences in transport with varying mass number, we find a strong mass dependence of transport in the edge of L-mode and H-mode plasmas [3-5]. These observations and simulations for the edge region are consistent with the isotope mass dependence in the L to H power threshold, which yields crucial information on the physics mechanism behind the edge transport barrier [7-8].

Neutral beam injection is the main heating source in AUG and JET H-modes and it is also a source for fast ions and torque in the plasma. Due to the mass dependence in the fast-ion slowing down time and the plasma inertia, studies with different isotopes allow us to separate the impact of the fast-ion content and the plasma rotation from the heating power and electromagnetic effects. The rotation or velocity shearing and dilution due to low levels of fast ions is captured well by reduced theoretical models like TGLF. Deviations are still observed at high beta and high fast-ion content where non-linear gyrokinetic simulations can provide an explanation for the observations [9].

Studies with different main ions let us access new parameter variations which directly improve our understanding of the underlying physics, because the plasma physics need to be valid regardless of the main ion mass.

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