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First-time demonstration of the three-ion scheme for radio-frequency heating in deuterium-tritium plasmas at the Joint European Torus

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The three-ion schemes have recently emerged as an effective method for plasma heating by radiofrequency (RF) waves in plasmas predominantly made by deuterium or hydrogen [1]. The schemes rely on the acceleration of a minority absorber (with a typical concentration of less than 1%) when the main plasma is made by two majority species, for example D-^{3}He or H-D, and that determine the wave polarization.

An important application of the schemes, as predicted by theory, is the capability to efficiently accelerate heavy impurity ions, such as ^{9}Be in a machine with a beryllium wall, and in reactor relevant deuterium-tritium plasmas. Due to their large critical energy, the fast impurity ions are then expected to transfer their energy predominantly to bulk ions by Coulomb collisions, resulting in an increase of the ion temperature and, hence, in an enhanced fusion rate by thermonuclear reactions.

In this talk, we present the first-time demonstration of heavy impurity heating with the three-ion scheme in deuterium-tritium plasmas of the Deuterium Tritium 2 experimental campaign (DTE2) of the Joint European Torus (JET). The experiments were conducted in 2021 and consisted in 5 successful pulses in plasmas of deuterium with a concentration of tritium in the range 50% to 75%, at a core magnetic field B_T=3.7 T and plasma currents between 2 MA and 2.5 MA. Neutral Beam Injection (NBI) at a moderate power in the range 2 MW to 8 MW was used to sustain the plasmas and was complemented with ion cyclotron resonance heating (ICRH) at power levels of about 2 MW with core deposition on ^{9}Be impurities. Evidence of the successful energy transfer from the fast heavy impurities to bulk plasma ions was shown by several signals. The plasma stored energy was found to increase by about 0.28 MJ/MW when ICRH was applied, as compared to 0.20 MJ/MW in NBI only phase. This was accompanied by a steepening of the ion temperature (T_i) profile as measured by charge exchange recombination spectroscopy (CXRS) and which extrapolates to an increase of the core ion temperature from 4 keV to 5 keV for phases with NBI only and with combined NBI and ICRH, respectively. Further evidence of increased thermal ion heating induced by ICRH was provided by neutron diagnostics. A ≈40% increase of the global neutron emission in the ICRH phase was observed together with a peaking of the neutron profile in the core, as determined by the neutron cameras. Novel synthetic diamond detectors [2] were used to measure the thermal and beam-target contributions to the neutron emission and showed an increase of the former component in the ICRH phase, in agreement with the enhancement of T_i. As counterproof of ^{9}Be acceleration, we have performed discharges where the D:T ratio was varied from 50:50 to 75:25 which, according to theory, makes the RF power absorbed predominantly by the tritium beam in lieu of ^{9}Be. This was experimentally demonstrated by the observed variations of the thermal and beam-target contributions to the neutron spectrum measured by diamond detectors. As a second goal of the experiment, we were also able to demonstrate measurements of the fusion power by means of the detection of the spectrum of 17 MeV gamma-rays produced by $d+t \rightarrow {}^5He+\gamma$ reactions, which has an interest in view of developing an alternative method to neutron diagnostics for the determination of the fusion power in a reactor.

The implications of these results for bulk ion heating of deuterium-tritium plasmas of next step tokamaks will finally be discussed, especially with reference to the use of extrinsic impurities in lieu of ^{9}Be as the ICRH absorber in machines that do not have beryllium as their first wall material.

References

[1] Y. Kazakov et al. Physics of Plasmas 28 020501 (2021)

[2] M. Nocente et al. Rev. Sci. Instrum. 93 093520 (2022)