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Energize Hydrogen Ions via Beam-Driven Ion Bernstein Waves in pB^{11} Plasmas

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Proton-boron fusion is regarded as a highly promising fusion scheme due to the abundance of its raw materials in nature and its neutron free reaction products. However, due to bremsstrahlung radiation, proton-boron fusion is challenging to achieve under thermal equilibrium where electron and ion temperatures are equal. R. M. Magee and B. S. Nicks discovered that injecting hydrogen neutral beams into a deuterium background plasma could generate high-energy background ion distributions and enhance the yield of nuclear reactions [1, 2]. In this research, we further theoretically analyze the wave generation condition induced by a hydrogen neutral beam injection into hydrogen-boron plasmas. The theoretical findings indicate that in the multi-component hydrogen-boron plasmas, ion Bernstein wave can transfer energy directly to background hydrogen ions and hardly to boron ions, which is helpful to the realization of hydrogen-boron fusion. Notably, the ion Bernstein wave excited by the neutral beam is highly correlated with Alfven velocity, and changing the ratio of hydrogen and boron will obviously affect its growth rate while keeping the electron density unchanged. Besides, we have demonstrated the mechanism responsible for generating the high-energy background ion distribution through simulations. The simulation results show that the ion Bernstein wave can produce high-energy hydrogen ions that deviate from Maxwell distribution and this principle is expected to produce hydrogen-boron fusion gain. The energy conversion obtained in the simulations are consistent with the theoretical results, and most of the energy of the wave is transferred to hydrogen ions, which may have an important impact on the heating mode of ions.

References

[1] Magee, R. M., et al. "Direct observation of ion acceleration from a beam-driven wave in a magnetic fusion experiment." Nature Physics 15.3 (2019): 281-286.

[2] Nicks, B. S., et al. "Beam-driven ion-cyclotron modes in the scrape-off layer of a field-reversed configuration." Nuclear Fusion 61.1 (2020): 016004.

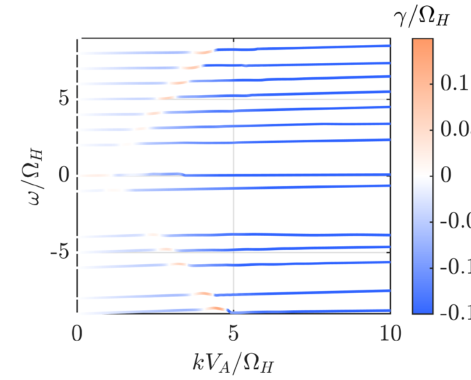

Figure 1. Instability excited by the neutral beam. Orange indicates growth, and blue indicates damping.

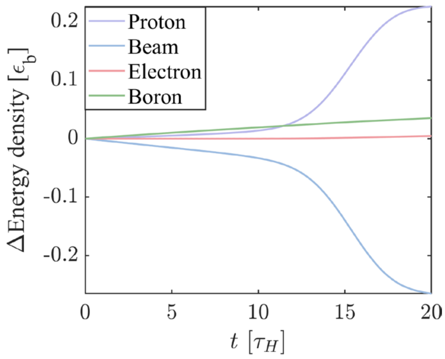

Figure 2. Temporal evolution of the particle energy density.

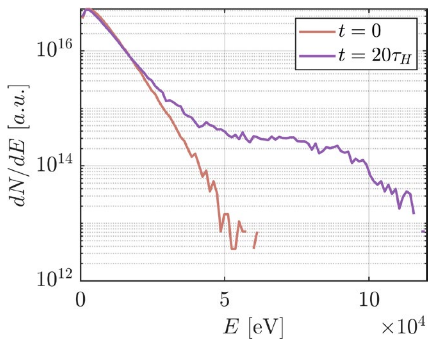

Figure 3. The hydrogen ion energy spectrum for various time snapshots.