

Keeping the fire burning in a fusion reactor

Experiments on NSTX have revealed an unexpectedly rich spectrum of waves excited by super-Alfvénic deuterons, making NSTX a unique laboratory test bed for super-Alfvénic energetic ion physics.

Magnetic-confinement fusion reactors use a strong magnetic field to confine a hot plasma of deuterium and tritium ions. The fusion energy is released in reactions between deuterium and tritium ions, which produce a 3.5-MeV He ion (alpha particle) and a 14-MeV neutron. The neutron will be absorbed in a blanket, from which the heat will be extracted to produce electricity. The 3.5-MeV alpha will be confined by the magnetic field and will slow down through collisions to keep the plasma hot. For many reactor concepts, the alpha particle birth velocity will be faster than the Alfvén speed, the velocity with which Alfvén waves propagate along magnetic field lines, in some ways like the oscillations of a violin string or like sound waves in air. The alpha particles may then efficiently interact with the Alfvén waves and transfer their energy through resonant interactions. These waves are of concern in the design of a fusion reactor as they may cause the fast ions (neutral-beam ions and alpha particles) to escape before they have used their energy to heat the plasma.

Experiments on the National Spherical Torus Experiment (NSTX) have provided new information on how the waves cause losses of fast ions, and what we can predict about their behavior in reactors.

The National Spherical Torus Experiment (NSTX) located at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) is an advanced experimental device whose shape allows it to operate with a much weaker magnetic field, thus lower Alfvén speed than in conventional devices. NSTX, heated by high power beams of neutral deuterium atoms, routinely operates with a large population of fast ions whose velocity is higher than the Alfvén speed (simulating conditions in thermonuclear plasmas). Recent experiments on NSTX study how Alfvén waves interact non-linearly at large amplitude, increasing fast ion transport, and studied the impact of high plasma pressure on waves which result from the coupling of Alfvén waves to acoustic waves. Spectrographs of these instabilities are shown in Figure 1. Careful measurements of these waves and fast ions are being used to improve our understanding of the

interaction of the waves with the large fast ion population, improving our ability to predict confinement of fast ions in ITER and other fusion reactor concepts.

In particular, in experiments on NSTX, researchers have identified the threshold pressure of fast ions necessary to excite Toroidal Alfvén Eigenmodes, a type of Alfvén wave, to sufficient amplitude where the waves interact non-linearly with each other. Their interactions can result in a synergistic, explosive growth causing a large enhancement in fast ion transport. This type of interaction, difficult to simulate theoretically, is thought to be important in future fusion large devices. The mode amplitudes and structure are measured with an array of diagnostics, including microwave reflectometers and interferometers which can make measurements in the core of the plasma.

In addition to the Alfvén waves, plasmas also have acoustic waves, similar to sound waves in air. If the frequencies of the Alfvén and acoustic waves are similar, they can interact to form a kind of hybrid wave. In a second experiment, the interaction of an Alfvén Cascade wave and a form of acoustic mode was demonstrated. Alfvén Cascades are a collection of waves that cover a wide range of frequency space. Further, it was shown that at high β (ratio of plasma to magnetic pressure), this interaction can stabilize these potentially dangerous Alfvén Cascade waves. This is most significant for a fusion reactor based on the Spherical Torus concept (like NSTX) which typically operates at high β , whereas β would be too low in fusion reactors like ITER to stabilize the mode.

The interaction of Alfvén and acoustic waves can allow new waves at high β . An instability, identified as the beta-induced Alfvén Acoustic eigenmode (BAAEs), was discovered in experiments. These are again hybrid modes resulting from the coupling of Alfvén waves and acoustic waves. BAAEs appear in the high plasma beta conditions when Alfvén Cascade modes are stabilized. They also can transport fast ions, but in addition to that they can be used to diagnose plasma parameters, such as the internal value of the magnetic field pitch angle. This is invaluable for the reactors based on the Spherical Torus concept where strong radiation makes other diagnostics measurements very challenging.

An invited talk by N. Crocker (JI1.2) to be presented at the 49th Annual Meeting of the APS Division of Plasma Physics in Orlando, FL will describe Alfvén wave research on the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL).

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