Fast-ion D-Alpha Measurements of the Fast-ion Distribution Function*

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The fast-ion D-alpha (FIDA) diagnostic is based on charge-exchange recombination spectroscopy. Fast ions that neutralize in an injected neutral beam emit Balmer-alpha light with a large Doppler shift. The spectral shift is exploited to distinguish the FIDA emission from the other bright sources of D_α light. Background subtraction is the main technical challenge; beam modulation and nominally identical "passive" views that miss the neutral beam are both employed. A spectroscopic diagnostic typically achieves spatial, temporal, and energy resolution of ~3 cm, ~1 ms, and ~10 keV, respectively. Installations that use narrow-band filters achieve high spatial and temporal resolution at the expense of spectral information. For high temporal resolution, the bandpass-filtered light goes directly to a photomultiplier, allowing detection of ~100 kHz oscillations in FIDA signal. For two-dimensional spatial profiles, the bandpass-filtered light goes to a charge coupled device (CCD) camera; detailed images of fast-ion redistribution at instabilities are obtained.

The relationship between the measured FIDA signals and the fast-ion distribution function is complex. The fast-ion distribution function is usually expressed as a function of energy, pitch (with respect to the magnetic field), and space. Since the Doppler shift only depends on one component of the velocity, light at a given wavelength is produced by ions with a range of energy and pitch. Qualitatively, a particular measurement is conveniently described by a weight function (or instrument function) in velocity space.

Different viewing geometries are used to diagnose different parts of the distribution function. For quantitative comparison between theory and experiment, forward modeling is required. The predicted fast-ion distribution function is input to a FIDA simulation code that includes atomic physics effects such as the charge-exchange neutralization probability and the collisional-radiative transitions that determine the fraction of neutralized fast ions that emit Balmer-alpha light.

The first quantitative comparisons between theory and experiment on DIII-D found excellent agreement in beam-heated MHD-quiescent plasmas. (Similar comparisons are in progress for other devices.) FIDA diagnostics are now in operation at magnetic-fusion facilities worldwide. They are used to study fast-ion acceleration by ion cyclotron heating, to detect fast-ion transport by MHD modes and microturbulence, and to study fast-ion driven instabilities.

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