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Instabilities Driven by Energetic Particles in Magnetized Plasmas[1]

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Wave heating, beam injection, and fusion reactions create super-thermal ion and electron populations in both natural and laboratory plasmas. The free energy of the energetic particles often drive instabilities. In this review talk, the generic features of these instabilities will be discussed using a class of instabilities known as Alfvén eigenmodes, which occur in spectral gaps associated with periodic variations in the index of refraction. In the first observations of these instabilities, intense neutral beam injection into tokamaks drove instabilities in the spectral gap caused by toroidicity. Later observations worldwide showed the universality of this phenomenon with a wide variety of energetic populations driving instabilities in numerous spectral gaps in stellarators, pinches, and spherical and conventional tokamaks. The extraction of energy from the energetic particles necessarily alters their constants of motion, leading to a degradation in confinement. Both convective and diffusive transport are observed and, in extreme circumstances, the vessel walls are damaged. Recent diagnostic advances show that the measured mode structure is often in excellent agreement with theoretical predictions; on the other hand, the observed fast-ion transport is often larger than expected. The nonlinear dynamics is complex. In some circumstances, bursts of wave activity cause fast-particle loss, resulting in relaxation oscillations. In others, structures in phase space associated with a single coherent mode cause frequency sweeping. In still others, multiple unstable modes result in gradual flattening of the fast-particle pressure profile. The many possibilities pose a challenge for ITER, where intense alpha-particle populations are likely to excite Alfvén eigenmodes.

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