Understanding the mechanism of alpha channelling

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Alpha channelling is a mechanism to transfer the power associated with the fusion-generated alpha particles to the thermal ions through the interaction with an externally excited wave, rather than relying on classical electron slowing down. In its simplest form, the mechanism relies on the interaction between fusion alphas and a high-frequency wave (typically a mode-converted Ion Bernstein Wave). The high-frequency wave extracts the kinetic energy associated with perpendicular motion through a resonant interaction that breaks the magnetic moment invariance. The extraction of energy is associated with a radial diffusion towards the plasma edge. A low-frequency wave (typically belonging to the Alfvén spectrum) can in turn displace the particles to the plasma edge. The mechanism has been proposed about 20 years ago [1] but little evidence exists both from experimental data and numerical simulations. The aim of this work is to provide a solid theoretical basis to this mechanism.

In the model considered here the effect of the high frequency wave is modeled via a quasi-linear diffusion operator whereas the low frequency wave is modeled via a boundary condition of outward particle flux Q at the boundary in phase space where the high-frequency wave induced diffusion vanishes. The associated Fokker-Planck equation (for simultaneous diffusion in space and energy) has been analytically solved in different ranges of the parameter space in order to understand the transition from wave damping to wave amplification (alpha channelling). It is shown that alpha channelling can take place only if the region in which the fusion alpha particles are generated is connected with the plasma boundary. Explicit expressions for the fraction of power transferred to the high-frequency wave have been derived and their dependence on Q analyzed.

The conditions for the validity of the quasilinear approach (i.e. the transition to stochastic behavior for the alpha particle orbits in phase space) will be also discussed.

In parallel, the problem of extracting kinetic energy associated to the parallel motion of alpha particles by means of a low-frequency Alfvénic wave has been addressed in the frame of hybrid MHD-particle simulations performed by the XHMGC code. The effect of injecting an Alfvén wave has been modeled by introducing a forcing term in the MHD equations solved by XHMGC. This term allows for establishing an Alfvén mode in the plasma, whose amplitude and radial structure depends both by input parameters and the interaction with bulk plasma and alpha particles. Initial studies have investigated under which conditions the Alfvén wave can extract a large fraction of kinetic energy from the alpha particle distribution and displace the exhausted alphas by a large fraction of the minor radius. The case of a large aspect ratio magnetic equilibrium was considered (a/R=10). A wave characterized by toroidal number n=2 and frequency located in the toroidal gap was forced by the antenna term. The possibility of extracting a fraction of the energy from the alpha population was shown, along with the capability of the wave to displace alphas by a relevant fraction of the minor radius.

[1] N.J. Fisch \& J.M. Rax, Phys. Rev. Lett. 69, 4, 612 (1992)