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Progress in understanding alpha channelling

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ABSTRACT

- Alpha channelling is a method to transfer fusion alphas energy to a high frequency wave (typically an Ion Bernstein Wave) that in turn is absorbed by the thermal ions [1]. The transfer occurs via stochastic heating. Particles receive a kick along the cyclotron orbit if their perpendicular velocity is $>\omega/k_y$ i.e. for $\mu B>E_w=(m/2)(\omega/k_y)^2$
- Diffusion in energy and space are tied together. A change $\Delta\mu$ produces a radial displacement $\Delta x=-[k_y/(Ze\omega)]\,\Delta\mu$. However, to extract the 3.5MeV and simultaneously displace an alpha from the center to the edge requires very large IBW toroidal mode numbers: $n_\varphi\sim(a/\rho_\alpha)^2$.
- A second low-frequency wave (typically an Alfvén mode) facilitate the particle ejection and allows channelling at moderate values of n_φ.
- Alpha channeling could increase ITER margins by operating in the hot-ion mode.

BACKGROUND

- Alphas are reflected at the magnetic axis and are lost at the plasma boundary. This asymmetry allows a net cooling.
- Not all the diffusion paths connect the source to the wall. Paths that end at $\mu B=E_w$ correspond to particles bouncing back and forth between the boundaries and slowly transferring energy to the electrons. However if an outward radial flux at $\mu B=E_w$ is assumed (e.g. due to the low frequency mode) a net transfer to the IBW results.
- Can we find an Alfvén spectrum that performs this job?
- The argument above, valid for a slab geometry [2], can be generalized to toroidal geometry [3] and are illustrated for a ITER equilibrium. The IBW is produced via mode conversion at the DT hybrid frequency and absorbed at the tritium cyclotron resonance [4].

METHODS

•SOLUTION OF THE FOKKER-PLANCK EQUATION

•An asymptotic solution of the steady-state Fokker-Planck equation for the distribution function has been determined in the limit of IBW diffusion time much shorter than the slowing down time. The analytic solution depends on the radial flux Q imposed at the boundary $\mu B=E_w$ [2,3] (see Fig.1).

•IBW PROPAGATION AND ABSORPTION

•The IBW ray equations have been analytically solved and the absorption by electrons and thermal ions evaluated in term of the poloidal extension of the IBW at the mode conversion layer and its parallel refractive index [4].

- ORBIT CODE SIMULATIONS

•The ORBIT code has been used to analyze the particle dynamics in the presence of a prescribed wave diffusion, particle slowing down and an imposed Afven eigenmode spectrum [5].

•Preliminary simulations with the PIC code HMGC have also been made

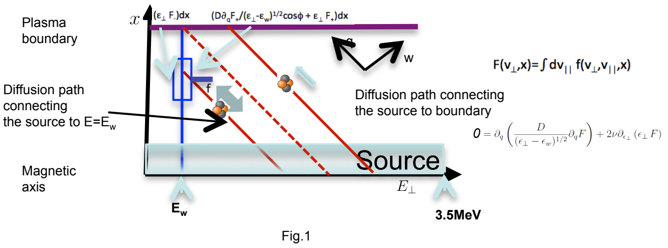


Fig.1

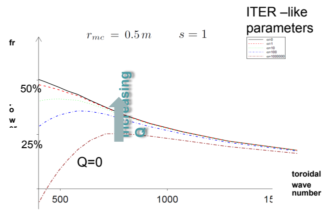
RESULTS

- MAXIMUM AMOUNT OF ALPHA CHANNELLING
- With a suitable choice of the outward flux Q a substantial effect can be obtained also for low IBW toroidal mode numbers (Fig.2).

- REQUIREMENTS ON IBW SPECTRUM
- The requirements on the IBW to avoid electron absorption are very stringent. The wave must be localized in the poloidal direction and the parallel refractive index ad the mode conversion must be <1 [4].

- PARTICLE DIFFUSION IN AN Alfvén EIGENMODE SPECTRUM
- Simulations performed with the ORBIT code [5] show that alpha particles can be ejected by the interaction with the AEs even at high energy, resulting in losses above the wall damage limit (5% in ITER).

Fig. 2. If Q=0
-Transferred power limited to ~25%
- Large toroidal wave numbers are needed (≈700)
- Negative transfer (wave absorption) at smaller toroidal wave numbers
By increasing the low-frequency wave flux the maximal power increases and moves to smaller toroidal wave numbers. [2, 3]



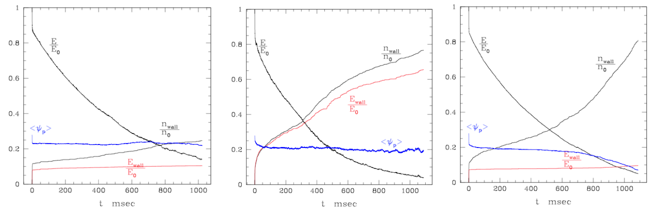


Fig.3. ORBIT code simulations using IBW induced diffusion and either AEs with different amplitude (a and b) or microturbulence with a diffusion coefficient decreasing as $E^{-3/2}$. Particles are cooled by the IBW and the second wave displaces the particle tothe boundary. However in all the cases the energy to the wall is above the ITER limit for wall damage (5%) [5].

CONCLUSIONS

- Alpha particle cooling is possible via a sufficiently large amplitude IBW.
- The cooled down distribution remains localized in the plasma core unless large IBW toroidal mode number are used.
- The use of Alfvén eigenmodes to facilitate the cooled alphas ejection produces also a loss of energetic alphas at a level too high for ITER.
- The use of AEs or microturbulence facilitates the cooled alphas ejection but the energy losses are above the limit for wall damage.
- The requirements on the IBW to avoid electron absorption appears to be very stringent.

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