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ANOMALOUS ALPHA-PARTICLE TRANSPORT IN THERMONUCLEAR TOKAMAK PLASMA

D.J. SIGMAR*
Oak Ridge National Laboratory
Oak Ridge, Tennessee

H.C. CHAN
Massachusetts Institute of Technology,
Cambridge, Massachusetts,
United States of America

ABSTRACT. Because of the strong localization of the fusion-born alpha particles in velocity and configuration space and their coupling to Alfvén waves in the background plasma, the relaxation of alphas is anomalous. In a finite system, the enhanced electromagnetic fluctuations can produce rapid spatial losses of alpha population and energy. These losses prevent the alpha velocity distribution from attaining a stable collisional equilibrium, thus maintaining a steady-state turbulence level. A self-consistent numerical quasi-linear calculation is performed for one of the most dominant low-frequency modes, showing the evolution of the alpha distribution and yielding the anomalous loss rates.

1. INTRODUCTION

The next generation of large neutral-beam-heated tokamaks is expected to reach ion temperatures high enough to produce significant amounts of alpha particles. So far, all the transport codes we are aware of have assumed collisional (neo)classical alpha dynamics. Provided the plasma current is chosen large enough, this results in perfect (if slow) deposition of the alpha energy in the plasma, but leads to undesirable alpha-particle diffusion toward the centre. A desired anomalous alpha behaviour (caused by instabilities) would consist of enhanced slowing down and *outward* diffusion.

Alpha particles are born with a velocity distribution function

$$f_\alpha \sim \delta(E - E_\alpha)$$

where $E_\alpha = 3.5$ MeV, and a spatial distribution

$$n_\alpha = t\langle\sigma_f v\rangle\, n_d n_t$$

where $\langle\sigma_f v\rangle \propto T^{-2/3} \exp[-20/T^{1/3}]$ is strongly peaked in the hot reactor core, as is the density product $n_d n_t$. In fact, in the absence of anomalous alpha diffusion, typically one-half of the alpha energy is contained inside one-fourth of the reactor radius. Thus, one suspects that this very collisionless, hot alpha component has a large amount of free energy which, because of the velocity ordering

$$v_{thi} < c_A < v_\alpha < v_{the} \qquad (1.1)$$

can be released via Alfvén wave instabilities. (Here the subscripts stand for ion, Alfvén, alpha, and electron velocity.) Since the first papers by Kolesnichenko and Oraevskij and by Korablev [1] on thermonuclear instabilities in 1967/68, a large number of such linear instabilities have been found; reviews of these findings were published recently by Lominadze et al. [2] and Bhadra [3]. (We note that neutral beam-driven instabilities have a much weaker, unstable wave-particle interaction, since for that case $v_{beam} < c_A$ in Eq.(1.1).)

Among these instabilities the high-frequency ($\omega \geqslant \omega_{ci}$, the ion gyrofrequency) short-wavelength modes are known to produce rapid velocity space relaxation and little spatial diffusion while the converse holds for low-frequency modes.

The alpha component should be unstable to both classes of modes simultaneously, depending on the required alpha threshold density for each. Since the low-frequency modes tend to have a lower threshold, they are expected to go unstable first. If, after their

* On leave of absence from Massachusetts Institute of Technology.