On the Electric Pedestal

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Abstract

This contribution examines an often-overlooked aspect of pedestal physics — the maintenance of over-all charge neutrality in the presence of ion loss arising from finite- banana width departures from closed flux surfaces. A negative radial electric field E_r' and current density $j_r = \sigma \ E_r'$ build up to assure that the total current remains divergence-free. Here, E_r' is to be evaluated in the frame rotating with the plasma and σ is a neoclassical conductivity called the orthogonal conductivity. The argument for the orthogonal conductivity is straightforward. Let us suppose a non-ambipolar process has induced a radial electric field E_r' in the plasma in addition to the electric field associated with a general toroidal rotation. In response to this field, the trapped ions execute a toroidal processional drift $v_\varphi = E_r' c/B_\theta$. Through ion-ion collisions, these particles exert a toroidal acceleration on the bulk plasma given by

$$F_\varphi = n_t \, M \, \frac{E_r c}{B_\theta} \, \nu_{ii} = n \, M \, R \, \frac{d\Omega}{dt} \qquad (1)$$

where Ω denotes the circulating ion toroidal rotation rate. The corresponding azimuthal drag force on the precessing trapped particles gives rise to a generalization of the Ware pinch with $F_\varphi/n_t e$ replacing E_φ. The pinch velocity is

$$v_r = \frac{M \, E_r \, \nu_{ii} c^2}{e \, B_\theta^{\ 2}} = \left(\frac{F_\varphi}{e \, n_t}\right)\frac{c}{B_\theta} \qquad \text{and} \qquad j = n_t \, e \, v_r = f_t \, \frac{n \, e^2 \, \nu_{ii}}{M \, \Omega_\theta^{\ 2}} \, E_r = \sigma \ \ E_r \qquad (2)$$

where f_t is the fraction of trapped ions. The model further supposes that ions are electrostatically confined and in thermal equilibrium. Consequently, density and potential variations are coupled via n_i exp(-eΦ/T); any density variation has a potential variation and E_r'. The rate of ion orbit loss, which drives the system, is controlled by the rate at which an ion can, by energy diffusion, exceed the confining electrostatic potential. This rate, too, depends on the potential through the density. All these elements can be combined into a second order differential equation, which supports spontaneous development of high gradient regions. The electrostatic, thermal-equilibrium confinement model implies an isotropic velocity distribution for the ions and consequently ions have no net velocity or contribution to bootstrap currents, which are carried instead by electrons.

*Work supported by U.S. Department of Energy under Contract DE-AC02-76CH03073