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A power-balance model of density limit in fusion plasmas

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A density limit (DL), causing either a disruption or a soft termination of the discharge, is generally found in magnetic confinement fusion devices. Some empirical scaling laws have been proposed to order the maximum achievable densities. The Sudo density, n_Sudo∝(P⊠ B⊠_ϕ)^0.5 [1], with P the heating power, is generally applied to the stellarator. The Greenwald density, n_G=I_p/((π a^2)) [2], represents a reference for the ohmic tokamak and the Reversed Field Pinch (RFP): a remarkable feature given the differences of these two configurations both in terms of magnetic profiles and transport properties. Additionally heated tokamak experiments in L-mode suggest scaling laws of the form P^(0.3÷0.5) I_p^(0.5÷1) [3, 4]. The H-mode tokamak DL, identified by a back transition to L-mode and therefore non disruptive in general, seems to be more device dependent [5, 6]. We present a basic power-balance model [7], providing a unified interpretation of DL in the stellarator, in the L-mode tokamak and in the RFP. In fact, scaling laws resembling the above empirical trends, but richer in their parametric dependence, are derived as special cases of a more fundamental relation, which delimits the thermal equilibrium states having realistic temperature profile (i.e. with low temperature only at the edge) in the presence of radiation losses due to light impurities and edge neutrals. This equation is just the detachment condition discussed in [8] within the stellarator framework. Our analysis shows that it can be applied to any magnetic configuration. In particular, by combining this equation with on-axis Ohm's law and Spitzer's resistivity, a Greenwald-like scaling law is obtained, having a tenuous dependence on thermal transport: this explains why the DL does not change appreciably passing from the ohmic tokamak to the RFP. Nonetheless, this scaling departs from the pure Greenwald limit, due to further dependences on the impurity content as well as on the heating power. We show that it describes better than the pure Greenwald limit high density disrupted L-mode experiments performed at TCV and JET.

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