Direct drive by cyclotron heating can explain spontaneous rotation in tokamaks

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Spontaneous plasma rotation during ion and electron cyclotron wave heating has been observed in Alcator C-Mod, DIII-D, JET, and Tore Supra, despite the lack of auxiliary mechanical momentum input.[1] Previous theoretical explanations for this spontaneous rotation were based on neoclassical effects, radial orbit shifts of cyclotron-heated energetic ions, turbulence-induced toroidal stress, or ion pressure gradient-driven electrostatic modes.[2] Here we provide an alternative explanation by showing that cyclotron wave heating can directly drive intrinsic tokamak plasma rotation through resonance with the precessional motion of trapped particles. Even with the cyclotron heating applied symmetrically, without a preferred toroidal direction, we find that, when FLR effects and magnetic field inhomogeneity are taken into account, the toroidal momentum input due to cyclotron wave heating is unbalanced in the toroidal direction. The cyclotron-heated fast particles can transfer their momentum to the bulk plasma through collisions. Using quasilinear theory, we have calculated the toroidal torque exerted on the plasma by cyclotron waves and established a relationship between the toroidal momentum input and the energy input. Our theory reproduces many characteristic features of spontaneous rotation: (a) scaling with stored energy and plasma current; (b) rotation direction for ICRF heating (co-current) and ECH (counter-current); (c) rotation direction for off-axis heating during ITB discharges; (d) inverted rotation profile during the L-H mode transition; (e) magnitude of rotation; and (f) inter-machine scalings with normalized beta and temperature ratio.[3] Our theory does not explain spontaneous rotation observed in purely Ohmic tokamak plasmas, which is smaller and mostly in the edge region; recent work[4] has shown another mechanism for this case. For core rotation, our theory provides significant agreement with experimental observations.

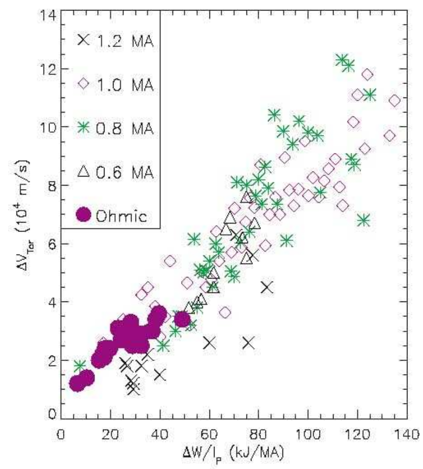

FIG. 1: Experimental scaling in Alcator C-Mod [from Rice *et al.*, Nucl. Fusion **41**, 277 (2001)]

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