Rotation properties of tokamak plasmas

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Recent theoretical developments in producing a comprehensive description of the rotation properties of tokamak plasmas are reviewed [1,2]. The calculation proceeds by employing a multiple timescale approach that distinguishes various physical effects that influence rotation evolution. In particular, the roles of 3-D magnetic fields and the effect on toroidal flow are emphasized. When the amplitudes of 3-D fields are sufficiently small, the timescales for poloidal flow evolution are vastly different than the timescale for toroidal flow evolution. On the ion-ion collisional timescale, parallel momentum balance predicts the damping of the poloidal ion flow to a diamagnetic level driven by ion temperature gradients. On longer transport timescales, radial force balance then implies the evolution of the radial electric field and toroidal flows are inextricably tied together. A transport equation for the toroidal flow can then be formulated [1] that accounts for collisional perpendicular viscosities, anomalous transport due to turbulence, momentum sources and neoclassical transport based viscous forces due to 3-D magnetic fields or neoclassical toroidal viscosity (NTV). The non-resonant components of the 3-D fields produce a toroidal torque of the form

$$\frac{\partial\Omega}{\partial t} = -\mu_{\|}(\nu_i, E_r)(\frac{\delta B}{B})^2[\Omega - \Omega_*]$$

throughout the plasma that relaxes the toroidal flow Ω to an "offset" velocity Ω_* proportional to the ion temperature gradient. Additionally, the damping rate $\mu_{\|}$ is a generally a function of the radial electric field (or Ω) and peaks at $E_r = 0$. Efforts to validate the existence of the off-set rotation [3] and nonlinear dependencies in the NTV damping rate [4] will be discussed. Finally, we note that the machinery developed to describe toroidal rotation in tokamaks can also be applied to quasi-symmetric stellarators.

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