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Why Magnetically Confined Plasmas Rotate and Why it is Important[1]

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Rotation in tokamak and spherical tokamak magnetic confinement devices has been found to be critical to enhancing the plasma stability to both the electron and ion gyroradius scale-turbulence as well to magnetohydrodynamic (MHD) modes whose characteristic scales can be of order the device size. Suppression of these modes leads to reduced energy and particle transport losses in these plasmas, thus increasing the potential fusion power production. Rotation can also lead to the avoidance of catastrophic MHD events known as "disruptions." This strong impact of the rotation underscores the importance of developing the knowledge of how rotation is generated in these devices and how the momentum is transported through the plasma. Rotation in these plasmas is generated by a number of different torques, including external momentum input from neutral beam injection, and magnetic torques (toroidal viscosity) resulting from a non-axisymmetric magnetic field structure. One leading theory suggests that rotation can also be self-generated from microturbulence. In this strongly coupled, predator-prey-like system, the plasma can self-organize from a turbulent state to one with directed flow in directions both parallel and perpendicular to the magnetic field. The rotation in the perpendicular direction is often seen to have radial structure and is analogous to the Zonal Flows observed in planetary atmospheres. The self-generated, or intrinsic, rotation that flows mainly along the magnetic field, has been measured on virtually all experimental devices. The theory suggests that the intrinsic torque generating the intrinsic rotation is due to long-wavelength (of order the ion gyroradius) modes, and experimental measurements of intrinsic torque and rotation generally follow the trends predicted by theory. Values of the momentum diffusivity and convective pinch term have been determined from perturbation experiments, and their trends indicate that the same modes that drive intrinsic rotation appear to be those responsible for the transport of momentum through the plasma. The results from conventional and spherical tokamaks are quite similar. While these studies offer a window into turbulent processes that can generate the flow as well as transport the momentum, other effects, such as torques due to lost particles and the effect of flows just outside the plasma boundary, can also be important. Developing an understanding of how all these processes interact is crucial for being able to predict rotation profiles and stability in future, fusion power generating devices, such as ITER.

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