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Transport Barriers: Controlling Turbulence in Confined Plasmas[1]

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One of the scientific success stories of fusion research over the past decade is the development of the $E \times B$ shear stabilization model to explain transport reduction and the formation of transport barriers in magnetic confinement devices. The fundamental physics involved in transport reduction is the effect of spatial variation (shear) in the $E \times B$ velocity on the growth, radial extent, and phase correlation of turbulent eddies in the plasma. This confinement improvement is of considerable physical interest; it is not often that a system self-organizes to a higher energy state with reduced turbulence and transport when an additional source of free energy is applied to it. The transport decrease associated with $E \times B$ velocity shear also has significant practical consequences for fusion research. The best fusion performance to date has occurred in tokamak plasmas where $E \times B$ shear stabilization effects are present. The $E \times B$ shear model was originally developed to explain the transport barrier formed at the plasma edge in tokamaks after the L–mode (low confinement mode) to H–mode (high confinement mode) transition. Similar, more recent results in stellarators and mirror machines are also consistent its predictions. More recently, the model has been applied to explain the further confinement improvement from H–mode to VH-mode (very high confinement mode) seen in some tokamaks, where the edge transport barrier becomes wider. Most recently, this paradigm has been applied to the core transport barriers formed in plasmas with negative or low magnetic shear in the plasma core. The same fundamental transport reduction process can be operational in various portions of the plasma because there are a number ways to change the radial electric field. Considerable experimental work has been done to test this picture of $E \times B$ velocity shear effects on turbulence; the experimental results are generally consistent with the basic theoretical models. A key factor in establishing this consistency has been the development of novel diagnostics to determine turbulence levels and $E \times B$ shearing rates as well as improved theoretical calculations of turbulence thresholds.

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