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Experimental Constraints on Transport from Dimensionless Parameter Scaling Studies[1]

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The related methods of dimensional analysis, similarity, and scale invariance in physics provide a powerful technique for analyzing physical systems. Since the scale invariance principle can serve as a framework for an empirical as well as a theoretical approach to plasma physics, the dependence of cross-field transport on dimensionless quantities such as the relative gyroradius (ρ_*), plasma beta (β), normalized collisionality (ν), and safety factor (q) has been measured on the DIII–D tokamak. Experimentally determining these dimensionless parameter scalings helps to differentiate between various proposed mechanisms of turbulent transport and allows the confinement properties of future magnetic fusion devices to be extrapolated from existing experiments. For example, experiments on DIII–D find that the beta scaling of heat transport for L-mode plasmas is close to zero, while for H–mode plasmas, the combination of a favorable beta scaling for ions and no beta dependence for electrons results in a weak (favorable) beta scaling of confinement. This weak or possibly non-existent beta scaling favors models of anomalous heat transport for which $E \times B$ transport is dominant over magnetic flutter transport. Drift wave models of anomalous transport can be further differentiated by their predicted dependence on collisionality. No ν dependence of heat transport is found for L–mode plasmas on DIII–D, which implies that the dissipative trapped electron and ion modes and resistive ballooning modes are not significant at any radii, although the result is consistent with the existence of η_i and collisionless trapped electron modes. A moderate, unfavorable ν scaling is observed in H–mode plasmas, which may be a manifestation of neoclassical transport. Experiments on DIII–D have also measured a strong safety factor scaling of heat transport at fixed magnetic shear for H–mode plasmas. Finally, ρ_* scaling experiments find gyro-Bohm-like scaling of electron heat transport in both L–mode and H–mode plasmas on DIII–D, as well as gyro-Bohm-like scaling of particle transport, which is the expected ρ_* dependence for turbulence generated by small-scale instabilities. However, the ρ_* scaling of ion heat transport varies from gyro-Bohm-like in ITER-relevant H–mode plasmas to Bohm-like or worse in L–mode plasmas, which indicates that the ρ_* scaling of transport is more complicated than the predicted power-law form. The ρ_*, β, and ν scalings of heat transport for H–mode plasmas are supported by similar experiments on JET. These dimensionless parameter scalings lead to a more optimistic projection for H–mode confinement on larger machines than the statistical database scalings developed for ITER, thus favoring the direction of compact, high-β machines for ignition devices.

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