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Understanding energy confinement in Wendelstein 7-X

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The W7-X stellarator has been optimized for low neoclassical transport and has achieved confinement times exceeding 200 ms at high densities and temperatures well above 3 keV in pellet-fuelled plasmas. Neoclassical transport calculations indicate that similar density and temperature profiles could not have been attained in less optimized magnetic configurations of W7-X or other stellarators scaled to the same volume and magnetic field strength, since the neoclassical energy flux would then have exceeded the total heating power. The magnetic geometry also serves to limit the turbulent transport. Unlike in tokamaks, trapped particles need not be localized to regions of bad curvature, which reduces the drive for trapped-electron modes. Ion- and electron-temperature-gradient-driven (ITG/ETG) modes remain, but can be stabilized by the density gradient that results from pellet injection. This theoretical expectation is a likely explanation for the improved confinement in plasmas with pellets, and is supported by gyrokinetic simulations. An increased radial electric field may also help to suppress turbulence under these circumstances. In electron-cyclotron-resonance-heated plasmas without pellets, turbulent transport is strong enough to limit the ion temperature to values below 2 keV. Recent gyrokinetic simulations suggest that this limitation is due to strong ITG turbulence when the electron-to-ion temperature ratio becomes large. With the addition of more heating power, higher-density operation is likely to lead to higher ion temperatures. The fact that turbulent transport can be reduced by tailoring the magnetic-field geometry in ways that are understood theoretically is encouraging and suggests that additional optimization could further improve confinement in stellarators.