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Electron Heat Transport in Improved Confinement Discharges in DIII–D[1]

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Under favorable conditions in DIII–D and other tokamaks ($q_0 > 1$, weak or negative central magnetic shear, sufficient beam heating), an internal transport barrier (ITB) is formed. Within the ITB, ion thermal transport is reduced, often to neoclassical levels. This effect has been explained by sheared $E \times B$ flow stabilization of turbulence.[2] In most such discharges, however, electron thermal transport remains anomalously large. This paper reports on recent experimental and theoretical studies of the physics underlying the electron behavior. In DIII–D, the condition $\omega_{E\times B} > \gamma$ is satisfied for long wavelength turbulence ($k_\theta \rho_\mathrm{s} < 1$) within the ITB,[2] where γ is the theoretically calculated linear growth rate for long wavelength modes (ITG, TEM, TIM), indicating that the $E \times B$ shearing rate stabilizes the turbulence.[3] Recent experiments with electron cyclotron and fast wave electron heating in DIII–D have examined the possible role of short wavelength turbulence ($k_\theta \rho_\mathrm{s} > 1$) for electron transport. For comparison with experiment, gyrokinetic linear instability theory[4] was used to calculate linear growth rates of toroidal drift waves: ion and electron temperature gradient modes (ITG, ETG) and trapped ion and electron modes (TIM, TEM). In typical plasmas, ETG modes are predicted to be unstable and large enough to increase electron transport. Due to their short wavelengths, $\gamma_\mathrm{ETG} > \omega_{E\times B}$, and flow shear stabilization is ineffective for electrons. In some plasmas, regions where $\nabla T_\mathrm{e}^\mathrm{exper} \approx \nabla T_\mathrm{e}^\mathrm{ETG}$ (critical gradient for onset of ETG instability) are often observed within the ion ITB. The tendency toward marginal stability implies a likely role for the ETG mode. Outside the ITB, both the electron and ion diffusivities increase and $\nabla T_\mathrm{e}^\mathrm{exper} > \nabla T_\mathrm{e}^\mathrm{ETG}$. In some discharges, certain regions within the ITB are ETG stable, implying that other effects may produce anomalous electron transport. Negative core loop voltage and outward flow from the Ware pinch may play a role in transient discharges with strong density peaking and rapidly rising core bootstrap current.

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