MORE ON $T_e$ EDGE PEDESTAL PROPERTIES

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Major Points From 2/9/05 Talk:

- Paleoclassical $\chi_e$ is likely dominant for $T_e \lesssim 1$ keV ($B^{2/3}/\#^{1/3}$)

- Basic edge pedestal hypothesis being explored is that $n_e(\rho)$ is determined from edge ionization source model [Mahdavi et al., PoP 10, 3984 (2003)]; then, $T_e(\rho)$ is determined by $\chi_e^{pc}$ from separatrix inward a couple of cm – until drift-wave-type turbulent transport dominates

Outline:

- Recall Some Key Viewgraphs From Last Time
- Paleoclassical $\chi_e$ Predictions Near A Separatrix
- Predicted Scaling Of Pedestal $T_e$
- Recommendations For Further Analysis
Motivation For Paleoclassical Studies Near Separatrix

- Since $D_\eta \propto \eta \propto 1/T_e^{3/2}$, $\chi_e^\text{pc}$ in the confinement region is typically

$$\chi_e^\text{pc} \sim 1.5 \frac{Z_{\text{eff}}}{[T_e(\text{keV})]^{3/2}} \frac{m^2}{s} > 1 \text{ m}^2/\text{s} \text{ for } T_e \lesssim 2 \text{ keV}$$

- Microturbulence-induced transport usually has a gyroBohm scaling:

ITG, DTE: $\chi_i^\text{gB} \equiv \# \frac{q_s T_e}{a_e B} \simeq 3 \# \frac{[T_e(\text{keV})]^{3/2} A_i^{1/2}}{a(m) [B(T)]^2} \frac{m^2}{s} > 1 \text{ m}^2/\text{s} \text{ for } T_e \gtrsim 0.5 \text{ keV} / \#^{2/3}$

ETG: $\chi_e^\text{gB} \equiv \#_e \frac{q_e T_e}{a_e B} \simeq 0.1 \#_e \frac{[T_e(\text{keV})]^{3/2}}{a(m) [B(T)]^2} \frac{m^2}{s} > 1 \text{ m}^2/\text{s} \text{ for } T_e \gtrsim 5 \text{ keV} / \#_e^{2/3}$

- Thus, paleoclassical $\chi_e^\text{pc}$ is likely to be dominant for $T_e \lesssim 1 \text{ keV}$ ($B^{2/3}/\#^{1/3}$)

- In DIII-D the electron temperature $T_e$ in the edge pedestal region ranges from about 100 eV at the separatrix to about 1 keV at top of pedestal

$$\Rightarrow \text{paleoclassical } \chi_e^\text{pc} \text{ likely to be dominant in pedestal region}$$
Approximate Forms Of $\chi_e^{pc}$ Predictions Near A Separatrix

• On the separatrix $\chi_e^{pc}$ is just the toroidal periodicity result:

$$\chi_e^{pc} \simeq \frac{3}{2} \frac{\eta^{{Sp}}_\parallel}{\mu_0} \simeq Z_{\text{eff}} \left[ \frac{100}{T_e(\text{eV})} \right]^{3/2} \frac{\text{m}^2}{\text{s}}$$

$$\implies \quad 2 \, \text{m}^2/\text{s} \text{ for DIII-D separatrix assuming } T_{e\text{sep}} \simeq 100 \, \text{eV} \text{ and } Z_{\text{eff}} \simeq 2$$

• Moving inside the separatrix $\chi_e^{pc} \propto T_e^{-3/2}$ decreases as $T_e$ increases until $q$ decreases to less than $q(\rho^s) \equiv (\lambda_e/\pi R_0)(\eta_{\text{nc}}^{\parallel}/\eta_{\text{nc}}^{\parallel}) \sim 3\text{--}30$ in DIII-D

$$\implies \quad \text{for DIII-D } \chi_e^{pc} \text{ decreases as } T_e^{-3/2} \text{ until } q \lesssim 3 \text{ (L-mode) or } 30? \text{ (H-mode)}$$

• Further into the plasma $\chi_e^{pc}$ is in the “collisional paleoclassical regime” and has Alcator-type scaling:

$$\chi_e^{pc} \simeq \frac{3}{2} \frac{\eta_{\text{nc}}^{\parallel}}{\eta_0} \frac{v_{Te}}{\pi R_0 q} \frac{c^2}{\omega_p^2} \propto \frac{T_e^{1/2}}{n_e q}, \text{ until } \lambda_e > \pi R_0 q n_{\text{max}} \sim 20 R_0 q \sim 100 \, \text{m at } q \sim 3,$$

beyond which $\chi_e^{pc} \propto T_e^{-3/2}$ and turbulence-induced transport likely becomes important
Comparison To DIII-D Near-Separatrix Data (Next VG)

- Paleoclassical predictions to be compared with DIII-D data are:

  1) positive curvature $(\partial^2 T_e/\partial \rho^2 > 0)$ of $T_e$ profile near separatrix — since $\chi_e^{pc} \sim 1/T_e^{3/2}$,
  2) gradient of $T_e$ increases moving inward from separatrix — until $q(\rho) < q(\rho^s) \sim 3-30$,
  3) At $\rho = \rho^s \sim 0.95-0.98$, $T_e(\rho^s) \simeq [n_e(\rho^s)/n_e(1)]^2 T_e(1) \implies \eta_e \equiv L_{n_e}/L_{T_e} = 2$,
  4) collisional regime (Alcator-type scaling) for $\rho \leq \rho^s \implies T_e$ independent of $n_e$.

- DIII-D L-mode data (D.G. Whyte et al. submitted to PPCF 10/04):

  $T_e(1) \simeq 100$ eV, max $\vec{\nabla}T_e$ at 2 cm inside separatrix, $[n_e(\rho^s)/n_e(1)]^2 \simeq 1.2^2 = 1.44$

  $\implies$ 1) $\partial^2 T_e/\partial \rho^2 \gtrsim 0$, 2) max $\vec{\nabla}T_e$ at $\rho^s \simeq 0.95$, 3) $T_e(\rho^s) \simeq 150$ eV, 4) $T_e \not\propto n_e$

- DIII-D H-mode data (T.H. Osborne, private communications 2/04, 2/9/05):

  $T_e(1) \simeq 100$ eV, max $\vec{\nabla}T_e$ about 0.8 cm inside separatrix, $[n_e(\rho^s)/n_e(1)]^2 \simeq 6$

  $\implies$ 1) $\partial^2 T_e/\partial \rho^2 > 0$, 2) max $\vec{\nabla}T_e$ at $\rho^s \simeq 0.98$, 3) $T_e(\rho^s) \simeq 500$ eV, 4) ? on $T_e \not\propto n_e$

- Paleoclassical predictions for $T_e$ pedestal profile shape, width:

  1) For $\rho \geq \rho^s$, $T_e(\rho) \sim n_e(\rho)^2 \sim \tanh^2(\delta x/\Delta_n)$, 2) $1-\rho^s$ is only relevant width parameter
Compare DIII-D H-Mode Edge Data To Paleoclassical Model

1) For $2.274 \lesssim R \lesssim 2.282$ ($\sim R_{\text{sep}}$), $\partial^2 T_e/\partial \rho^2 \gtrsim 0$, positive curvature

2) $\vec{\nabla} T_e$ maximum around $R \sim 2.274$ ($\sim 0.08$ cm inside separatrix, $\rho^s \gtrsim 0.98$)

3) $T_e(2.274) \sim 500$ eV $\sim 5T_{e\text{sep}}$, while $[n_e(\rho^s)/n_e(1)]^2 \sim 6$

4) For $R < 2.274$ ? on $T_e$ dependence on $n_e$

Data courtesy of T.H. Osborne (unpublished, 2004, and most importantly on 2/9/05)
Reflections On Paleoclassical Predictions Near Separatrix

- Predicted $q$ where $\chi_{\text{pc}}$ changes from near-separatrix form to Alcator-type scaling is very sensitive to $T_e$ at position where maximum $|\partial T_e/\partial \rho|$ occurs:

  in H-mode example $q(\rho^s) \sim 30 \left( T_e/500 \text{ eV} \right)^2 \implies 7.5$ if $T_e(\rho^s) \simeq 250$ eV

- There may be some additional effects of the local (rather than global) magnetic shear very near the separatrix (as suggested by Brennan, Snyder) — my near-separatrix theoretical analysis still needs to be revisited

- In the Alcator scaling regime the paleoclassical profile prediction is

  $$T_e \simeq T_e(\rho^s)[1 + c_0 P_e x - c_1 |dP_e/d\rho|x^2]^{2/3} \sim 1 + x - x^2 \text{ with } x \equiv \rho^s - \rho \geq 0$$

  — instead of $1 + \tanh x \sim 1 + x - x^3$

- The estimation (on next viewgraph) of a pedestal electron temperature with the point where the drift-wave-type anomalous electron heat diffusivity is equal to the paleoclassical diffusivity might seem to conflict with ELM stability analysis — but in this model the $T_e^\text{ped}$ is not necessarily representative of $\vec{\nabla} P$ because the maximum $|\partial T_e/\partial \rho|$ occurs at $\rho^s$ not $\rho^\text{ped}$
Scaling Of Pedestal Electron Temperature

- Assume the pedestal electron temperature $T_{\text{ped}}^e$ is determined by the radial position $\rho_{\text{ped}}$ where the drift-wave-type turbulent electron heat diffusivity (use $\chi_{e}^{\text{dw}} \simeq \chi_{i}^{\text{dw}}/3$ and $\chi_{i}^{\text{dw}} = f_{\#} \varrho_{s}^{2} c_{s}/a$) is equal to the paleoclassical value:

  drift-wave turb: $\chi_{e}^{\text{dw}} \propto f_{\#} T_{e}^{3/2}/a B^{2}$ in which $f_{\#} \simeq f_{\#}(T_{i}/T_{e}, \hat{s}, \nu_{*e}) \sim (T_{i}/T_{e})^{\alpha \hat{s} \beta \nu_{*e}^{\gamma}}$

  paleoclassical: $\chi_{e}^{\text{pc}} \propto Z_{\text{eff}} (\eta_{\|}^{\text{nc}}/\eta_{0}) / T_{e}^{3/2}$ with (for DIII-D) $\eta_{\|}^{\text{nc}}/\eta_{0} \simeq 0.45 + 2/(1 + \nu_{*e}^{1/2} + \nu_{*e})$

- Equating these electron heat diffusivities yields a $T_{e}$ pedestal scaling

  $$T_{e}^{\text{ped}} \simeq 0.5 B(T)^{2/3} \left( \frac{a}{0.67 \text{ m}} \right)^{1/3} \frac{[(Z_{\text{eff}}/2) (\eta_{\|}^{\text{nc}}/2\eta_{0})]^{1/3}}{[f_{\#}(T_{i}/T_{e}, \hat{s}, \nu_{*e})/6]^{1/3}} \text{keV} \propto B^{2/3} \left[ \frac{aZ_{\text{eff}} (\eta_{\|}^{\text{nc}}/\eta_{0})}{f_{\#}} \right]^{1/3}$$

- Tom Osborne will exhibit some of his attempts to determine whether these predicted scalings are relevant to DIII-D edge pedestal data in next talk
Recommendations For Further $T_e$ Pedestal Analysis

- Fit the edge $T_e(\rho)$ profile differently:
  \[
  \tanh^2 x \text{ outside } \rho^s \text{ (point where maximum } |\partial T_e/\partial \rho| \text{ occurs), and different function for } \rho \leq \rho^s = \tanh x \text{ with changed } \Delta_T \text{ or a different function?}
  \]

- Continue scaling studies of $T_{e,\text{ped}}/B^{2/3}$ versus key dimensionless parameters:
  - electron collisionality $\nu_{*e}$, temperature ratio $T_i/T_e$, and magnetic shear $\hat{s} \equiv (\rho/q)(dq/d\rho)$

- Use ONETWO modeling of near-ohmic discharges (shot #’s 90765, 90118, 90761) to explore
  1) comparison of $\chi_{e,pc}$ to power balance $\chi_e$
  2) $T_e$ profiles predicted by paleo-classical model for $\chi_e$

- Develop ONETWO modeling capability for edge pedestal analysis with paleo-classical model and explore
  1) edge $T_e(\rho)$ profile and relation to $n_e(\rho)$ determined by neutral ionization model
  2) radial position $\rho^{\text{ped}}$ and the $T_{e,\text{ped}}$ at which $\chi_{e,pc} = \chi_{e,dw}$