Paleoclassical Model: Minimum Transport Levels*

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The paleoclassical model [1] of radial electron heat transport was compared [2] with experimental results from 7 toroidal devices at the recent IAEA Chengdu meeting. The general conclusion [2] from the 18 different comparisons is that paleoclassical transport may set the irreducible minimum (factor ~ 2) level of radial electron heat transport in many resistive, current-carrying toroidal plasmas. In particular, since the low collisionality regime paleoclassical $\chi_e^{\rm pc}$ scales as $a^{1/2}/T_e^{3/2}$, whereas the gyroBohm diffusivity scales as $T_e^{3/2}/aB^2$, paleoclassical transport is usually dominant for [2] $T_e < T_e^{\rm crit} \simeq B^{2/3}a^{1/2}$ keV ($\sim$ 1–1.5 keV in present experiments, but $\sim$ 5 keV in ITER), i.e., primarily in ohmic-level plasmas. However, if micro-turbulence is suppressed, paleoclassical transport can set the minimum level even when $T_e > T_e^{\rm crit}$ [2]. This presentation will: 1) present some of the experimental evidence [2] that the paleoclassical model sets the minimum level of radial electron heat transport, 2) advocate that paleoclassical transport be considered the lowest level of electron transport, 3) discuss possible extensions of the paleoclassical model to density, ion heat and toroidal momenmtum transport, and 4) highlight areas where additional research is needed.

Specific issues that need to be addressed to validate the paleoclassical model and improve predictive understanding of tokamak plasma transport include:

1) Explore regimes where paleoclassical radial electron heat transport sets the minimum level level of transport. A challenge: Can transport less than the paleoclassical level be achieved?

2) Consider micro-turbulence-induced transport to be only that in excess of paleoclassical. Plot paleoclassical $\chi_e^{\rm pc}$ on power balance χ_e graphs to show degree of "anomalous" transport.

3) Explore other plasma transport apparently induced by axisymmetric paleoclassical processes: density $[D^{\rm pc} \simeq D_\eta \equiv \eta_\parallel^{\rm nc}/\mu_0]$, ion heat $[\chi_i^{\rm pc} \simeq (3/2)D_\eta]$ and toroidal momentum $[\chi_\varphi^{\rm pc} \sim D_\eta]$ diffusion, all with pinch effects.

4) Develop algorithm for predictive transport modeling that takes account of different form of paleoclassical electron heat transport operator: $-\langle \boldsymbol{\nabla}\cdot \mathbf{q}_e^{\rm pc}\rangle = (1/V')(\partial^2/\partial\rho^2)[V'\bar{D}_\eta(3/2)n_eT_e]$.

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[1] J.D. Callen, a) Phys. Rev. Lett. **94**, 055002 (2005), b) Phys. Plasmas **12**, 092512 (2005), c) Nucl. Fusion **45**, 1120 (2005), and d) "Derivation of paleoclassical key hypothesis," UW-CPTC 06-8R, January 2007 (submitted to Phys. Plasmas).

[2] J.D. Callen, J.K. Anderson, T.C. Arlen, G. Bateman, R.V. Budny, T. Fujita, C.M. Greenfield, M. Greenwald, R.J. Groebner, D.N. Hill, G.M.D. Hogeweij, S.M. Kaye, A.H. Kritz, E.A. Lazarus, A.C. Leonard, M.A. Mahdavi, H.S. McLean, T.H. Osborne, A.Y. Pankin, C.C. Petty, J.S. Sarff, H.E. St. John, W.M. Stacey, D. Stutman, E.J. Synakowski, K. Tritz, "Experimental Tests of Paleoclassical Transport," paper EX/P3-2, IAEA Fus. Energy Conf., Chengdu, China, 16-21 Oct. 2006: http://www-pub.iaea.org/MTCD/Meetings/fec2006pp.asp (slightly extended version submitted to Nuclear Fusion).