Collisional Loss Calculations of Energetic Ions in NSTX

Martha H. Redi, PPPL

NSTX would benefit from a detailed theoretical study of energetic particle confinement,
including collisions, electric fields for both NBI and RF ions

Performance evaluation of heating efficiency
- **Reliable predictions for high beta**
- **Basis for use of BEAST, "between and among shot Transp",**
- **Permit theory-based modeling of local confinement of particles, energy**
- **Validate models of RF heating**

A new full, test particle collision model is developed and in use:
Monte Carlo guiding center codes, such as ORBIT/ORBIT3D

Compared to simple models: pitch angle scattering & slowing down for compact quasiaxially symmetric stellarator designs.
- **Neutral beam ion loss fractions are reduced from 41% to 25%**
- **Collisionless losses: 8% prompt & 9% stochastic passing.**

- ALREADY IN USE:

  NCSX: 40 MW beam ions in slowing down τ (EPS, 2000), 25% ion loss

  Simpler model (Phys. Plas. 2000) 41% loss…energy dependence

- ORBIT/ ORBIT3D code package upgraded

  with improved treatment of collisional effects;

  both particle pitch angle scattering and energy slowing down.

- Polynomial fit to the incomplete gamma function

  valid for slow and fast ions to <1%; asymptotically correct

- Radial profiles of background ion, impurity ion densities and Ti and Te

  control scattering rates radial resolutio

- Previous models used constant scattering rates

  or approximate radial fits to

  TRANSP pitch angle & energy slowing down scattering rates.

- · Effects of collisions in synergistically enhancing fast particle losses over collisionless estimates has been documented in modelling of TFTR, ITER and stellarator designs like NCSX.
- New collisional treatment: reliable accurate estimates of loss rates for beam ions and RF ions, etc from NSTX as well as other devices.

Examples of ORBIT/3D Collisional Calculations

(one slowing down time, particle losses)

- **TFTR Neutral beam ion**

  Collisional losses were 2x collisionless loss rates

- **Alpha particle**

  - Monotonic shear, high current case

  pitch angle scattering => losses to increase from 12 to 19%

  - **Reversed shear experiments (high q)**

  Collisions were found to increase losses less than 20%, collisionless stochastic diffusion was dominant

  Simulations of confined alpha distribution: good agreement with measurements with pellet charge exchange diagnostic.

- **ITER alpha particle losses**

  - **Monotonic shear: small, less than 2%, even w/sawtooth**
  - **Reversed shear, collisionless high: 14%**

- **Stellarator: NCSX candidate QAS2_20 - many ripple wells**

  - **Beam ion**

  Parallel inj: collisions increase losses x25

  Perp injection, losses increased by 2-40, depend on co/ctr

  - Scaled reactor: alpha particle

  Losses increase from <1% to 12% with pitch angle scattering

Test Particle Collision Operator for the ORBIT Code Package

- **Pitch** $\lambda' = \lambda (1 - \nu_\perp \Delta t) \pm [1 - \lambda^2)\nu_\perp \Delta t/2]^{0.5}$
- **Energy** $E' = E - 2\nu_E \Delta t\, [E - (3/2 + (E/\nu_E)\, \delta\nu_E/\delta E) T_b] \pm 2\, [T_b E \nu_E\, \Delta t]^{0.5}$

Boozer, Kuo-Petravic, Phys. Fluids (1981)

- **Earlier simulations used radially constant $\nu_\perp$ and $\nu_{E,}$, and only the first term in the evolution equation for energy**

- **From the NRL Formulary:**

$$\nu_\perp = 2\, [(1 - 1/(2x))\psi(x) + \psi'(x)]\, \nu_o = f\, \nu_o$$

$$\nu_E = 2\, [(m/m_b)\, \psi(x) - \psi'(x)]\, \nu_o = F\, \nu_o$$

$$\nu_o = 4\pi e^4 Z^2 Z_b^2 \ln\Lambda n_b / m^2 v^3, \text{ b = background}, \quad x = v^2/v_b^2 = E m_b / T_b m$$

- **Incomplete gamma function; approximated by $\psi_A(x) = 1 - 1/P(x)$**

A least squares fit to $P = 1 + x^{3/2} (a_o + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4)$
Asymptotically correct, is accurate to within 10^{-3},
and has ψ'/ψ relative error $< 10^{-2}$

Conclusions

Application of accurate collisional model to energetic ion orbit calculations will improve understanding of NSTX perfomance

- **New model is in use, benchmarked for QAS stellarators (Spong, ORNL), much improved over earlier simple model.**

- **Fast ions are not likely to be affected by anomalous transport:**
  Calculations verify validity of neoclassical transport for fast ions on TFTR and JT-60.

- **New complete collision model**
  Will be useful on NSTX for neutral beam ions and RF ion confinement

- **With diagnostics for RF and beam ion losses,**
  and crosschecks on electron and ion temperatures and densities
  Theoretically based models for
  - **Thermal transport and**
  - **Particle transport**
  - **RF heating can be tested**

PPPL
PRINCETON PLASMA PHYSICS LABORATORY