Fall Term 2002
Introduction to Plasma Physics I

22.611J, 6.651J, 8.613J

Problem Set #3

1. Calculate the mean free path for momentum loss (equal to the characteristic velocity divided by the collision frequency) for:

   (a) An electron at thermal energy in a tokamak plasma of equal electron and ion temperatures, $T \simeq 4 \ \ KeV$, and density, $n \simeq 10^{14} cm^{-3}$.

   (b) Calculate the electron mean free path for collisions with protons (momentum exchange), λ_c, and show that this mean free path greatly exceeds the Debye length, $\lambda_c \gg \lambda_D$. Now calculate the ratio, λ_c/λ_D, as a formula (not numbers), relate it to a fundamental plasma parameter, and show therefor why it is *always* large.

   (c) A thermal ion in the same plasma.

   (d) A thermal electron in a semiconductor processing plasma of temperature, $T \simeq 5 \ \ eV$, and density, $n \simeq 5 \times 10^{12} cm^{-3}$.

2. Consider the collisional relaxation of $\sim 3.5 \ MeV$ alpha particles produced by fusion reactions in a $50 : 50$ mixture $D - T$ plasma. Estimate the relaxation time (for energy loss) of the α's in a plasma at density, $n \sim 10^{14} cm^{-3}$. Consider the collisions with the 3 different species in the plasma. Assume, $T_e = T_D = T_T = 10 \ KeV$.

   (a) Which species is most effective at thermalizing (slowing down) the alpha particles?

   (b) Which plasma particles are preferentially heated by the α's?

   Hint: Start with α's at $3.5 \ MeV$ but then consider the different regimes of α energy as they slow down.

3. A toroidal hydrogen plasma with circular cross-section has uniform temperature, $T_e = 1 \ KeV$, across its minor radius, $a = 30 \ cm$. The major radius is $R = 120 \ cm$. Calculate the toroidal electric field, E_ϕ, required to drive a current of 4×10^5 *Amperes* (in cgs units, 1.2×10^{15} *StatAmperes*) the long way round the torus, and hence the required one-turn toroidal $E.M.F.$ (called the "loop voltage"). [You may do this calculation to lowest order in a/R, and adopt a generic value of the Coulomb logarithm, $\ln \Lambda = 16$.

   Calculate, ignoring relativity, the minimum parallel energy at which an electron becomes a *runaway* if the density of this plasma is $10^{13} cm^{-3}$. (You may use electron-ion collisions for this estimate). Does this energy justify your ignoring relativistic effects?

4. *Derivation of Fluid Equations from Moments of the Boltzmann Equation.* . . . saving this GREAT problem for next week!