EE507 – Plasma Physics and Applications

Homework #4

1) By now, you should be able to calculate several parameters that characterize low temperatures discharges used in plasma processing and other applications.

   i. Using the density-temperature plot given seen in Lecture 9, calculate the typical Debye length for processing plasmas. How does it compare to the size of the processing chambers seen in class?
   ii. A second defining attribute of a plasma is that it must contain a large number of particles inside a Debye sphere. Verify that this is satisfied in this case.
   iii. Another important property of a plasma is the time scale for Debye shielding to occur. Review early lectures to find a way to estimate the time that electrons take to correct charge imbalances on these plasmas.
   iv. We have seen that many of these plasmas are excited by RF power. What is the maximum excitation frequency that these plasmas can shield?
   v. Note that the product of the Debye length and the plasma frequency is the electron thermal velocity for a Maxwellian distribution. What are the typical electron thermal velocities for these plasmas?
   vi. Low-pressure plasmas are far from being in complete thermodynamic equilibrium with radiation because they are optically thin (the mean free path for photon absorption is much larger than the typical dimensions of the chambers). This allows these plasmas to reach temperatures of several eV without losing humongous amounts of power by black body radiation. Calculate how much radiation would be emitted by a 40-inch fluorescent bulb with a surface area of 0.05 m^2 containing a plasma at 1 eV if the plasma were a black body.
   vii. For an argon plasma with ion density of 10^{17} m^{-3}, calculate the *ion* plasma frequency. How does it compare to the *electron* plasma frequency for the same plasma?

2) The electron-neutral collision cross section for 2-eV electrons in He is about $6\pi a_o^2$, where $a_o = 0.53\text{x}10^{-8}$ cm is the radius of the first Bohr orbit of the hydrogen atom. A positive column with no magnetic field has $p = 1$ Torr of He (at room temperature) and $kT_e = 2$ eV.
   b. Compute the electron diffusion coefficient in m^2/sec, assuming that $<\sigma v>$ averaged over the velocity distribution is equal to σv for 2-eV electrons
   c. If the current density along column is 2 kA/m^2 and the plasma density is 10^{16} m^{-3}, what is the electric field along the column?

3) A weakly ionized plasma slab in plane geometry has a density distribution $n(x) = n_o\cos(\pi x/2L)$ for $-L \le x \le L$. The plasma decays by both diffusion and recombination. If $L = 0.03$ m, $D = 0.4$ m^2/sec, and $\alpha = 10^{-15}$ m^3/sec, at what density will the rate of loss by diffusion will equal the rate of loss by recombination?

4) You do a recombination experiment in a weakly ionized gas in which the main loss mechanism is recombination. You create a plasma of density 10^{20} m^{-3} by a sudden burst of ultraviolet radiation and observe that the density decays to half its initial value in 10 msec. What is the value of the recombination coefficient α?

5) A high-pressure, steady-state argon plasma discharge confined between two parallel plates located at $x = \pm\, l/2$ is created in argon gas at density n_g by uniformly illuminating the region within the plates with ultraviolet radiation. The radiation creates a uniform number G_o of electron-ion pairs per unit volume per unit time (m^{-3} s^{-1}) everywhere within the plates. Electrons and ions are lost to the walls by ambipolar diffusion. Assuming that the electron and ion temperatures are uniform and constant with time, with $T_e >> T_i$, and choosing boundary conditions such as $n(x) \approx 0$ at the walls, find the plasma density $n(x)$ and the peak density n_o within the plates.

6) An RF discharge is ignited between two parallel electrodes located at $x = \pm\, l/2$. The steady-state diffusion equation

$$\frac{d^2n}{dx^2} + \beta^2 n = 0$$

With the boundary condition that $n(\pm l/2) = 0$, has the solution $n(x) = n_o \cos(\pi x/l)$, where $\beta^2 = \nu/D_a = (\pi/l)$, ν is the electron-neutral ionization rate, and $D_a \approx \mu_i T_e$ is the ambipolar diffusion coefficient (T_e is in eV)

a. Find the steady-state (dc) particle flux $\Gamma(x)$, ambipolar electric field $E(x)$, potential $\Phi(x)$, and total charge density $\rho(x)$. Sketch Γ, E, and Φ for x within the plates.
b. Plot $\rho(x)/e$ and $n(x)$ on the same graph for x within the plates.
c. Find the steady-state diffusion velocity $u(x) = \Gamma(x)/n(x)$. Equating $u(x)$ to the Bohm velocity $u_B = (T_e/M)^{1/2}$, find the sheath thickness s (the thickness of the region near the electrode where $u(x)>u_B$). You may assume that $s << l/2$.