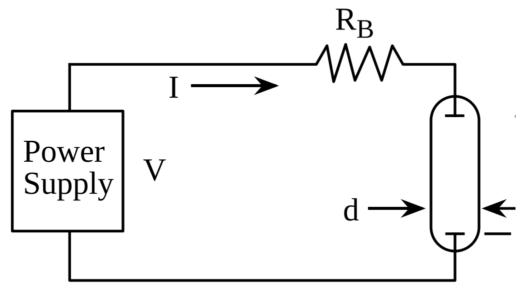
EECS 517 / NERS 578 FALL 2010 HOMEWORK #5

In this homework assignment, we will calculate the characteristics of a positive column glow discharge for realistic operating conditions. Use the following discharge circuit conditions



A cylindrical discharge tube (length *l*, diameter d) is connected in series with a DC power supply (voltage V) and series ballast resistor (R_B ohms). The gas pressure is 1 Torr at a gas temperature of 300 K ($N = 9.654 \times 10^{18}\ P_{Torr}/T_K$ cm^{-3}).

Use the cross sections for the ideal molecule and M = 20 AMU. Assume that the only <u>inelastic</u> energy loss process is electron impact ionization, and that electron loss is dominated by ambipolar diffusion. You may assume that the ion temperature, T_I is equal to the gas temperature. For these particular conditions, the plasma properties are obtained from the following:

Electron Temperature: Obtained from the electron continuity equation:

$$T_e: \quad \frac{\partial n_e}{\partial t} = 0, \qquad k_{ion}(T_e)N - \frac{D_A(T_e)}{\Lambda^2} = 0$$

(E/N): Obtained from the electron temperature equation:

$$\frac{E}{N}: \quad T_e = T_g + \left(\frac{2}{3k_B}\right)\left(\frac{M}{2m_e}\right)\left[\frac{q^2}{m_e k_m^2(T_e)}\left(\frac{E}{N}\right)^2 - \sum_i \frac{\Delta\varepsilon_i k_i(T_e)N}{N k_m(T_e)}\right]$$

Electron density: Obtained from the current density

$$n_e: \quad j = \frac{I}{\pi\left(\frac{d}{2}\right)^2} = \sigma E = \frac{n_e q^2}{m_e k_m(T_e)}\left(\frac{E}{N}\right)$$

Recall that collision frequencies are related to rate coefficients by $\nu_i = k_i N$

and that the ambipolar diffusion coefficient is $D_A(T_e) = D_I(T_I)\left(1 + \frac{T_e}{T_I}\right)$

where

T_e	Electron temperature (eV)
$k_{ion}(T_e)$	Rate coefficient for ionization (cm^3/s)
$k_m(T_e)$	Rate coefficient for momentum transfer (cm^3/s)
$k_i(T_e)$, $\Delta\varepsilon_i$	Rate coefficient for inelastic process i with energy loss $\Delta\varepsilon_i$ (cm^3/s, eV)

$D_A(T_e)$	Ambipolar diffusion coefficient (cm^2/s)
$D_I(T_I)$	Ion diffusion coefficient (cm^2/s)
$\Lambda = \frac{\frac{d}{2}}{2.405}$	Diffusion length for cylinder (cm)
T_g	Gas temperature (K)
T_I	Ion temperature (K)
k_B	Boltzmann's constant (1.6×10^{-12} erg/eV, 1.38×10^{-16} erg/K)
N	Gas density (cm^3)
M, m_e	Gas atom mass, electron mass (g)
q	Elementary charge (c)
j	Current density (A/cm^2)
I	Current (A)
σ	Conductivity (1/Ohm-cm)

1. Plot E/N, T_e, I (total current), V_{DIS} (voltage across the discharge tube) and n_e for the following parameters. Use $D_I = \frac{500\ cm^2}{s}$ at a pressure of 1 Torr.

$$L = 30\text{ cm},\quad j = 15\text{ mA/cm}^2,\quad 0.25\text{ cm} < d < 2.5\text{ cm}$$

Discuss why each of E/N, T_e, I, and V_{DIS} change or does not change as the diameter of the discharge tube is changed. You may use values of rate coefficients you derived in previous homework assignments. You *do not need* to rederive the rate coefficients here.

2. How will these values obtained in (1) change if j is increased to 25 mA/cm^2? Sketch your answers. (No additional numerical work is required.)

3. How will the values in (1) change if L is increased to 60 cm? Sketch your answers. (No additional numerical work is required.)

4. Suppose we add an external source of ionization, S_{ion}, so that

$$\frac{\partial n_e}{\partial t} \approx 0 = n_e\left(k_{ION}(T_e)N - \frac{Da(T_e)}{\Lambda^2}\right) + S_{ion}$$

The external source could be, for example, photo-ionization. How will T_e, n_e, E/N, V_{DIS} and I change as S increases? Assume *j* remains a constant. (Explain your answer in <u>words</u>, no calculations are required.)