16.522 Space Propulsion
Problem Set 3

We wish to design a 1 N thruster Xenon ion engine with a specific impulse of 2500 sec. The acceleration system will consist of extractor, accelerator and decelerator grids, with 1 mm gaps and with open area fractions of 0.2 and 0.8 to neutrals and ions, respectively. The net to total voltage ratio should be 0.7.

A propellant utilization fraction of 0.9 is desired. As initial estimates, assume $T_e = 2$ eV, $T_i = T_n = 400$ K and 4 secondary electrons produced per primary electron. The cylindrical side surface will be equal in area to each end surface of the engine.

1. Find V_{tot} and V_{net}.
2. What is the engine diameter D?
3. Find the ion and neutral particle densities (n_i, n_n) in the beam.
4. Find the beam current I_B, anode current I_A and cathode current I_C.
5. Find the voltage loss V_{loss} and calculate the thruster efficiency $\eta = \dfrac{V_{\text{net}}}{V_{\text{net}} + V_{\text{loss}}}$.
6. What is the ionization fraction α in the chamber?

HINTS:

Assume ions arrive at any surface at a rate $n_i v_B$ per unit area, per second ($v_B = \sqrt{\dfrac{kT_e}{m_i}}$). Neutrals arrive at $\dfrac{n_n \bar{c}_n}{4}$ ($\bar{c}_n = \sqrt{\dfrac{8kT_n}{\pi m_n}}$ and only a fraction of them (equal to the grid open fraction) escape. Electrons (both primary and secondary) are lost to the anode only, and they carry with them an energy $2kT_e$ per electron. Work is expended in creating ions ($V_i = 12.13$ V for Xenon), creating excited atoms that decay by radiation (assume another eV_i per created ion) and heating up electrons, plus, of course, in accelerating the beam. Use an energy balance with these terms to figure out V_{loss}.