Units and Best Practice

Units prove to be a confusing aspect of this course. The units which are commonly in use in the field are the "standard" for this course. Unfortunately, the units are "mixed" (that is, a mixture of cgs and mks). Some useful conversion factors are listed below. Some best practices you should follow are:

1. ALWAYS perform a units analysis and perform a "sanity" check to determine that your answer is reasonable. In most cases, "unreasonable" answers are a result of unit problems. For example, if your answer is that the argon ion density in a plasma etching reactor is $10^{50}$ ions/cm$^3$, your answer is unreasonable and you probably have a units problem. You know your answer is unreasonable since if the density is really $10^{50}$ argon ions/cm$^3$, the mass of 10 cm$^3$ of the plasma would be equal to twice the mass of the earth.

2. Never, ever be confused by expressing temperature in Energy Units (or vice-versa). Temperature in Energy Units ALWAYS Means

$$T \text{ (eV)} \equiv kT \text{ (eV)}$$

3. Unless specified otherwise, you final answers in homework problems should be expressed in the following units:

- Electron energies or temperatures
- Atomic or molecular energies or temperatures
- Lengths
- Electron, atomic or molecular masses
- Electron, atomic or molecular speeds
- Cross sections
- Mobilities
- Diffusion coefficients
- Rates coefficients (1st, 2nd, 3rd order)
- Electric fields
- Normalized Electric Fields
- Densities
- Power
- Power deposition (specific)
- Current density

- EV
- K or eV
- cm
- AMU or g
- cm/s
- cm$^2$ or A$^2$
- cm$^2$/V-s
- cm$^2$/s
- s$^{-1}$, cm$^3$/s, cm$^6$/s
- V-cm$^{-1}$
- V-cm$^{-2}$ or Td
- cm$^{-3}$
- W
- W-cm$^{-3}$
- A-cm$^{-2}$
Useful Conversion Factors

\[ k = 1.38 \times 10^{-16} \text{ erg/K} = 1.38 \times 10^{-23} \text{ J/K} \]

\[ 1 \text{ eV} = 1.6 \times 10^{-12} \text{ ergs} = 1.6 \times 10^{-19} \text{ J} = 11,594.2 \text{ K} \]

\[ q = e = 1.6 \times 10^{-19} \text{ C (coulomb)} = 4.8 \times 10^{-10} \text{ esu} \]

\[ 1 \text{ V} = 1 \text{ J/C} = 10^7 \text{ erg/C} \]

\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ [F/m or C}^2\text{/m-J]} = 8.85 \times 10^{-14} \text{ [F/cm or C}^2\text{/cm-J]} \]

\[ m_e \text{ (electron mass)} = 0.911 \times 10^{-27} \text{ g} = 0.911 \times 10^{-30} \text{ kg} \]

E/N: 1 Td (Townsend) = \(10^{-17} \text{ V-cm}^2 = 10^{-21} \text{ V-m}^2 = 0.354 \text{ V/cm-Torr at } (T = 273 \text{ K)} \]

\[ 1 \text{ Å}^2 = 10^{-16} \text{ cm}^2 = 10^{-20} \text{ m}^2 \]

1 atm = 760 Torr = 1.013 bar

Gas Density: \[ N = \frac{P}{kT} = 9.654 \times 10^{18} \frac{P(\text{Torr})}{T(\text{K})} \text{ cm}^{-3} \]

\[ 1 \text{ m}^3 = 10^6 \text{ cm}^3 \]
Useful Relationships

Electron speed for energy $\varepsilon$:

$$v = \left( \frac{2\varepsilon}{m_e} \right)^{1/2} = 5.93 \times 10^7 \left( \varepsilon (eV) \right)^{1/2} \text{cm/s}$$

Average electron thermal speed for temperature $T_e$:

$$v = \left( \frac{8kT_e}{\pi m_e} \right)^{1/2} = 6.69 \times 10^7 \left( T_e (eV) \right)^{1/2} \text{cm/s}$$

Debye Length:

$$\lambda_D = \left( \frac{\varepsilon_o k T_e}{n_e q^2} \right)^{1/2} = \left( \frac{k T_e}{4 \pi m_e q^2} \right)^{1/2} = 743 \left[ \frac{T_e (eV)}{n_e (cm^{-3})} \right]^{1/2} \text{cm}$$

Plasma Frequency:

$$\omega_p (\text{radian/s}) = \left( \frac{n_e q^2}{m_e \varepsilon_o} \right)^{1/2} = \left( \frac{4 \pi m_e q^2}{m_e} \right)^{1/2} = 5.64 \times 10^4 \left[ \frac{n_e (cm^{-3})}{cm^3} \right]^{1/2} \text{radians/s}$$

Rate coefficient:

$$k \left( \frac{cm^3}{s} \right) = < \sigma \cdot v > \ (\text{e.g.} \ (e.g. \ \frac{\partial N}{\partial t} = n_e k N))$$

$\sigma = \text{cross section cm}^2 \quad v = \text{velocity cm/s}$

Conductivity:

$$\sigma = \frac{n_e q^2}{m_e v_m} = 2.81 \times 10^{-4} \frac{n_e \left( cm^{-3} \right)}{v_m \left( s^{-1} \right)} \frac{1}{\Omega - cm}$$

$v_m = \text{electron momentum transfer collision frequency}$

Electron Mobility:

$$\mu_e = \frac{q}{m_e v_m} = 1.756 \times 10^{15} \left( \frac{cm^2}{V - s} \right)$$