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

<table>
<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energies or temperatures</td>
<td>eV</td>
</tr>
<tr>
<td>Atomic or molecular energies or</td>
<td>K or</td>
</tr>
<tr>
<td>temperatures</td>
<td>eV</td>
</tr>
<tr>
<td>Lengths</td>
<td>cm</td>
</tr>
<tr>
<td>Electron, atomic or molecular</td>
<td>AMU or</td>
</tr>
<tr>
<td>masses</td>
<td>g</td>
</tr>
<tr>
<td>Electron, atomic or molecular</td>
<td>cm/s</td>
</tr>
<tr>
<td>speeds</td>
<td>cm$^2$ or A$^2$</td>
</tr>
<tr>
<td>Cross sections</td>
<td>cm$^2$/V-s</td>
</tr>
<tr>
<td>Mobilities</td>
<td>cm$^2$/s</td>
</tr>
<tr>
<td>Diffusion coefficients</td>
<td>s$^{-1}$, cm$^3$/s, cm$^6$/s</td>
</tr>
<tr>
<td>Rates coefficients (1st, 2nd,</td>
<td>V-cm$^{-1}$</td>
</tr>
<tr>
<td>3rd order)</td>
<td>V-cm$^{-2}$ or</td>
</tr>
<tr>
<td>Electric fields</td>
<td>Td (10$^{-17}$ V-cm$^2$)</td>
</tr>
<tr>
<td>Normalized Electric Fields</td>
<td>cm$^3$</td>
</tr>
<tr>
<td>Densities</td>
<td>W</td>
</tr>
<tr>
<td>Power</td>
<td>W-cm$^3$</td>
</tr>
<tr>
<td>Power deposition (specific)</td>
<td>Amps-cm$^2$</td>
</tr>
</tbody>
</table>
Useful Conversion Factors

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

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

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

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

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

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

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 K)}

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

\[ 1 \text{ atm} = 760 \text{ Torr} = 1.013 \text{ bar} \]

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 $\varepsilon$:

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

Average electron thermal speed for temperature $T_e$:

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

Debye Length:

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

Plasma Frequency:

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

Rate coefficient:

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

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

Conductivity:

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

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

Electron Mobility:

$$\mu_e = \frac{q}{m_e v_m} = \frac{1.756 \times 10^{15} \text{ cm}^2}{v_m(s^{-1}) \frac{V}{s}}$$