Today, we will:

- Continue discussing **Section 1.5 - Fundamentals**
- Do some example problems

**GAS MIXTURES**

**Assumptions:**
- Well mixed
- Ideal gas

Let:
- \( T \) = temperature (actual \( T \) in the room)
- \( V \) = total volume (vol. of room)
- \( P \) = total pressure (\( \approx P \) if \( \cdots \))
- \( m_t \) = total mass (of all species, air + pollutants)
- \( n_t \) = total #mols (\( \cdots \) of \( \cdots \))

Volume contains \( N \) species \( j = 1, 2, 3, \ldots, N \).

**Equation:**

\[
    m_t = \sum_{j=1}^{N} m_j
\]

**Shortened:**

\[
    m_t = \sum_{j} m_j
\]

\( m_j \) = mass of species \( j \)

\[
    n_t = \sum_{j} n_j
\]

**Mass fraction** of species \( j \) = \[
    f_j = \frac{m_j}{m_t}
\]

**Mol fraction** \( \cdots \) = \[
    y_j = \frac{n_j}{n_t}
\]

Typical unit of mol fraction: **ppm** (parts per million) or **ppb** (parts per billion).
\[ P = \frac{n_j R T}{V_j} \]

\[ T = \frac{n_j R T}{V_j} \]

\[ \frac{P V_j}{n_j R T} = \frac{V_j}{V} = \frac{V_j}{V} \]

\[ \sum \frac{P V_j}{n_j R T} = \frac{V_j}{V} \]

Ideal gas law in terms of partial pressure:

\[ P_j V_j = n_j R T \]

Dalton's law of additive pressures:

\[ P = \sum P_j \]

If we assume that species \( j \) would exist on the wall if it were the only gas at \( P_j \) and \( T \), then the partial pressure \( P_j \) is the pressure it would exert in the container if \( n_j \) occupied the entire volume \( V \) at temperature \( T \).

\[ P_j = \frac{n_j R T}{V_j} \]
Similarly, \[
\frac{V_j}{V} = \frac{n_j R u T / \rho}{n_t R u T / \rho} = \frac{n_j}{n_t} = Y_j
\]

Summary:
\[
Y_j = \frac{n_j}{n_t} = \frac{P_j}{P} = \frac{V_j}{V}
\]

for ideal gas mixture

In most applications with air pollution, \(Y_j\) is very small \((\sim 10 \text{ ppm})\)

\[Y_j \ll 1\]

\[M_t \approx M_{\text{air}}\]

\[\forall \approx \forall_{\text{air}}\]

For liquids, similar definition, but use \(X\) instead of \(Y\)

\[X_j = \frac{n_j}{n_t} = \text{mol fraction of species } j \text{ in a liquid mixture}\]

(See text)
Example

Given:
- The mol fraction of CO in a room is $56 \text{ PPM}$.
- The molecular weight of CO is 28.0 kg/kmol.
- The temperature is $20^\circ\text{C}$ and the pressure is 99.5 kPa.

To do: Calculate the partial pressure of CO in the room.

Solution:

$$y_j = \frac{P_j}{P} \Rightarrow P_j = y_j P$$

$$= (56 \times 10^{-6}) (99.5 \text{ kPa})$$

$$P_j = 5.6 \times 10^{-3} \text{ kPa}$$ (to 2 sig. digits)

\[
C_{j} = \text{mass concentration} = \frac{m_j}{V}
\]

\[
\left\{ C_{j} \right\} = \left\{ \frac{m}{L^3} \right\} \text{ units typically} \frac{mg}{m^3}
\]

\[
C_{\text{molar},j} = \text{molar concentration} = \frac{n_j}{V}
\]

\[
\left\{ C_{\text{molar},j} \right\} = \left\{ \frac{\text{mol}}{L^3} \right\} \text{ units typ.} \frac{\text{mol}}{m^3} \text{ or} \frac{\text{kmol}}{m^3}
\]

\[
m_j = n_j M_j
\]

\[
f_j = \frac{n_j M_j}{V} = \frac{1}{M_j} \left( \frac{m_j}{V} \right) C_j
\]

\[
C_{\text{molar},j} = \frac{C_j}{M_j}
\]
\[ C_j = \frac{\dot{m}_j}{V} \]
\[ P_j V = \frac{m_j}{M_j} R u T = \frac{m_j}{M_j} R u T \]
\[ V = \frac{m_j}{M_j} \frac{R u T}{P_j} \]
\[ C_j = \frac{m_j}{m_j} \frac{M_j P_j}{m_j R u T} = M_j \left( \frac{P_j}{P} \right) \]
\[ C_j = y_j \frac{M_j P}{R u T} \]

Eq. (1-29)

**Note:**
- Mol fraction is independent of P \& T
- Mass concentration depends on P \& T
- Molar concentration \( \ldots \ldots \ldots \ldots \)
Example

Given:
- The bulk volume flow rate of an air/ammonia mixture is 1000 ACFM through a duct.
- The air contains 5.0 PPM of ammonia vapor ($M_{\text{ammonia}} = 17.0$).
- The temperature is 200.°C (473.15 K) and the pressure is 90. kPa.

(a) To do: Calculate the ammonia mass concentration.

Solution:

\[
C_j = y_j \frac{P}{T} \frac{M_j}{K_u} \quad \text{(Eq. 1-29)}
\]

\[
C_j = \left(5.0 \times 10^{-6} \frac{\text{mol amm}}{\text{mol}}\right)\left(90. \text{kPa}\right)\left(17.0 \frac{\text{g amm}}{\text{mol amm}}\right)\left(\frac{2.241}{\text{mol amm}}\right)\left(1000 \frac{\text{m}^3}{\text{kg}}\right)\left(1000 \text{mg amm}\right)
\]

\[
C_j = 1.94 \frac{\text{mg}}{\text{m}^3} \quad \text{of ammonia}
\]

\[
C_j = 1.9 \frac{\text{mg}}{\text{m}^3}
\]

(b) To do: Calculate the emission rate of ammonia into the atmosphere in g/hr.

Solution:

\[
\dot{m}_j = C_j Q_{\text{actual}} = \left[ C_j V_{\text{actual}} \right]
\]

\[
\dot{m}_j = (1.94 \frac{\text{mg}}{\text{m}^3}) \left(1000 \frac{\text{ft}^3}{\text{min}}\right) \left(0.3048 \frac{\text{m}}{\text{ft}}\right)^3 \left(60 \frac{\text{min}}{\text{hr}}\right) \left(1 \frac{\text{g}}{1000 \text{mg}}\right)
\]

\[
\dot{m}_j = 3.296 \frac{\text{g}}{\text{hr}} \quad \text{→} \quad \dot{m}_j = 3.3 \frac{\text{g}}{\text{hr}}
\]