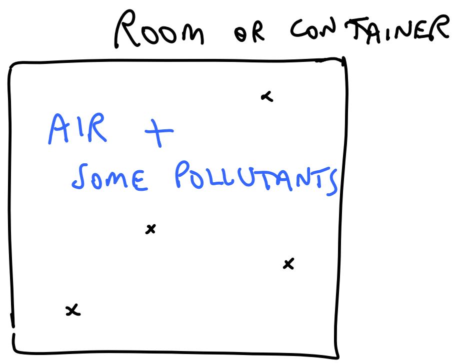
Today, we will:

- 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)

$\forall$ = total volume (vol. of room

P = total pressure (" P " . . .)

m_t = total mass (of all species, air + pollutants)

n_t = total # mols (" " ")

volume contains N species $j = 1, 2, 3 \ldots, N$

Equations:

$$\boxed{m_t \equiv \sum_{j=1}^{N} m_j}$$

shorthand: $m_t = \sum_j m_j$

m_j = mass of species j

$$\boxed{m_t = \sum m_j}$$

$$\boxed{n_t = \sum n_j}$$

Mass fraction of species j = $\boxed{f_j \equiv \frac{m_j}{m_t}}$

Mol fraction " " = $\boxed{y_j = \frac{n_j}{n_t}}$

typical "units" of mol fraction ppm (parts per million)

or ppb (" " billion)

Ideal Gas Law for the Bulk Mixture

$$\boxed{P\forall = n_t R_u T}$$

☆ DALTON'S LAW OF ADDITIVE PRESSURES:

$$\boxed{P = \sum_{j=1}^{N} P_j} \quad \left[\text{or } P = \sum P_j\right]$$

P_j = Partial pressure

$P_j \equiv$ pressure that species j would exert on the walls if it were the only species in the container @ the container volume $\forall$ & temperature T. ☆

Ideal gas law in terms of partial pressure:

$$\boxed{P_j \forall = n_j R_u T}$$

☆ Amagat's Law of Additive Volumes:

Let $\forall_j$ = partial volume ≡ volume that species j would occupy if it were the only gas at P & T

☆ $\boxed{P\forall_j = n_j R_u T}$ → Ideal gas law in terms of partial volume

$$\boxed{\forall = \sum_{j=1}^{N} \forall_j = \sum \forall_j} ☆$$

$$\frac{P_j}{P} = \frac{n_j \cancel{R_u T}/\cancel{\forall}}{n_t \cancel{R_u T}/\cancel{\forall}} = \frac{n_j}{n_t} = y_j$$

Similarly, $\frac{\forall_j}{\forall} = \frac{n_j \cancel{R_u} \cancel{T} / \cancel{p}}{n_t \cancel{R_u} \cancel{T} / \cancel{p}} = \frac{n_j}{n_t} = y_j$

Summary: $$\boxed{y_j = \frac{n_j}{n_t} = \frac{P_j}{P} = \frac{\forall_j}{\forall}}$$

for ideal gas mixtures

In most applications with air pollution,

y_j is very small (~10 ppm)

if $y_j \ll 1$, $M_t \approx M_{air}$

$\forall \approx \forall_{air}$

For liquids, similar definitions, but use X instead of y for mol fraction

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

(see text)

Example

Given:

- The mol fraction of CO in a room is 56 PPM. 56×10^{-6}
- The molecular weight of CO is 28.0 kg/kmol.
- The temperature is 20°C and the pressure is 99.5 kPa.

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

Solution:

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

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

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

Concentration

$$\boxed{c_j = \text{mass concentration} = \frac{m_j}{\forall}}$$

$$\{c_j\} = \left\{\frac{m}{L^3}\right\} \quad \text{units typically } \frac{mg}{m^3}$$

$$\boxed{C_{molar,j} = \text{molar concentration} = \frac{n_j}{\forall}}$$

$$\{C_{molar,j}\} = \left\{\frac{N}{L^3}\right\} \quad \text{\# of mols} \quad \text{units typ. } \frac{mol}{m^3} \text{ or } \frac{kmol}{m^3}$$

$$\boxed{m_j = n_j M_j}$$ ☆

$$C_{molar,j} = \frac{\overbrace{n_j M_j}^{m_j}}{\forall \; M_j} = \frac{1}{M_j} \overbrace{\frac{m_j}{\forall}}^{c_j}$$

$$\boxed{C_{molar,j} = \frac{c_j}{M_j}}$$ ☆

Other conversions:

$$C_j = \frac{m_j}{\forall} \quad ; \quad P_j \forall = n_j R_u T = \frac{m_j}{M_j} R_u T$$

$$\therefore \forall = \frac{m_j}{M_j} \frac{R_u T}{P_j}$$

$$C_j = \frac{\cancel{m_j} M_j P_j}{\cancel{m_j} R_u T} = M_j \underbrace{\frac{P_j}{P}}_{= y_j} \frac{P}{R_u T}$$

$$\boxed{C_j = y_j \frac{M_j}{R_u} \frac{P}{T}}$$ ☆ Eq. (1-29)

NOTE:
- Mol fraction is independent of P & T
- Mass concentration depends on P & T
- Molar concentration " " "

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 ($M_{ammonia}$ = 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: $c_j = y_j \frac{P}{T} \frac{M_j}{R_u}$ (Eq 1-29)

$$c_j = \left(5.0 \times 10^{-6} \frac{\cancel{\text{mol}}\ \text{amm}}{\cancel{\text{mol}}}\right)\left(\frac{90.\ \cancel{\text{kPa}}}{473.15\ \cancel{\text{K}}}\right)\frac{\left(17.0 \frac{\text{g amm}}{\cancel{\text{mol amm}}}\right)}{\left(8.314 \frac{\cancel{\text{J}}}{\cancel{\text{mol}\cdot\text{K}}}\right)}\left(\frac{\cancel{\text{J}}}{\cancel{\text{N}}\cdot\text{m}}\right)\left(\frac{1000\ \cancel{\text{N}}}{\text{m}^2\cdot\cancel{\text{kPa}}}\right)\left(\frac{1000\ \text{mg}_{\text{amm}}}{1\ \cancel{\text{g amm}}}\right)$$

$$\underline{c_j = 1.94 \frac{\text{mg}}{\text{m}^3}} \text{ of ammonia}$$

$$\boxed{c_j = 1.9 \frac{\text{mg}}{\text{m}^3}} \quad \text{(2 digits)}$$

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

mass per time

Solution:

$$\dot{m}_j = c_j Q_{actual} \quad \left[= c_j \dot{V}_{actual}\right]$$

$$= \left(1.94 \frac{\cancel{\text{mg}}}{\cancel{\text{m}^3}}\right)\left(1000 \frac{\cancel{\text{ft}^3}}{\cancel{\text{min}}}\right)\left(\frac{0.3048\ \cancel{\text{m}}}{\cancel{\text{ft}}}\right)^3\left(\frac{60\ \cancel{\text{min}}}{\text{hr}}\right)\left(\frac{1\ \text{g}}{1000\ \cancel{\text{mg}}}\right)$$

$$= 3.296\ \text{g/hr} \rightarrow \boxed{\dot{m}_j = 3.3\ \text{g/hr}}$$