

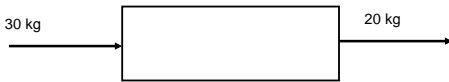
Chapters 5-6 (where we are going)

- Ideal gases and liquids (today)
 - Densities
 - Partial pressures
- Non-ideal gases (next time)
 - Eqns. of state
 - Reduced pressures and temperatures
 - Compressibility charts (z)
- Vapor-liquid systems (Ch. 6)
 - Vapor pressure
 - Humidity
 - Raoult's law
 - Bubble and dew points
 - Solid-solid & liquid-liquid systems

Class 15

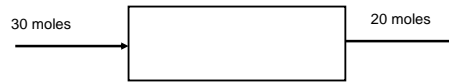
- Properties of Single Phase Materials
 - Connection to Material Balances
 - Ideal Assumptions
 - Liquids- density of mixtures
 - Ideal Gases
 - Standard conditions

Is the following possible?



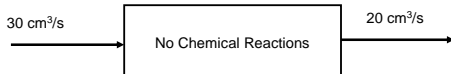
No!

Is the following possible?



Yes!

Is the following possible?



Yes!

Is the following possible?



Yes!

Need Relationships Between Variables

- Not easy to measure molar flow rates
- What can we easily measure?
- Relate measured variables to desired quantities

Liquid Mixtures



- In general, liquid volume is not conserved
 $V = V_1 + V_2 + V^E$
- Contraction or expansion occurs because of the difference in interactions between like and unlike molecules
- V^E typically small. Assume $V^E = 0$ for this course.
- This implies that liquid volumes are additive

$$\frac{1}{\rho} = \sum_{i=1}^n \frac{x_i}{\rho_i}$$

How does this relate to volume?

Example

- What is the density of a mixture containing 20 wt% A ($\rho_A = 1 \text{ g/cm}^3$) and the balance B ($\rho_B = 2 \text{ g/cm}^3$)?

$$\frac{1}{\rho} = \frac{0.2}{\rho_A} + \frac{0.8}{\rho_B} = \frac{0.2}{1} + \frac{0.8}{2}$$

Therefore, $\rho = 1.67 \text{ g/cm}^3$

If you used $\rho = \sum x_i \rho_i$, you would have calculated $\rho = 0.2*1 + 0.8*2 = 1.8 \text{ g/cm}^3$ Oops!

Gases

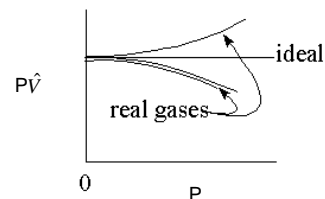
- **Equation of State** relates amount (moles), volume, T, P
- Many different equations of state-represent behavior of real systems
- **Ideal Gas Law**
 - Simplest equation of state
 - Most widely used



Ideal Gas

- Equation of State: **$PV = nRT$**
- Also $P\hat{V} = RT$ (i.e., $\hat{v} = V/n$)
- Assumptions
 - No interaction between molecules
 - Molecules have zero volume
- Valid at low concentration (n/V)
 - Best at high or low pressures?
 - Best at high or low temperatures?

Ideal vs. Real Gases



From p. 192, ideal when:

$$\hat{V}_{ideal} > 5L/mol \text{ (diatomic gases)}$$

$$\hat{V}_{ideal} > 20L/mol \text{ (other gases)}$$

Ideal Gas Constant

- In Chemistry and Chemical Engineering, **R** is universal (independent of species)
 - Nice table in the back cover of the book for different units
- In Mechanical Engineering, the MW of the species is included, so there is a different value of **R** for each species

Ideal Gas Constant

THE GAS CONSTANT

8.314 m ³ ·Pa/(mol·K)	} For ideal gas eqn
0.08314 L·bar/(mol·K)	
0.08206 L·atm/(mol·K)	
62.36 L·mm Hg/(mol·K)	
0.7302 ft ³ ·atm/(lb-mole·°R)	
10.73 ft ³ ·psia/(lb-mole·°R)	} For Energy
8.314 J/(mol·K)	
1.987 cal/(mol·K)	
1.987 Btu/(lb-mole·°R)	

Gas Concentration & Density

- Concentration = moles/volume = n/V

$$C = \frac{P}{RT} \quad \text{or} \quad C_i = \frac{P_i}{RT}$$

- Density = mass/volume = $n \cdot MW/V$

$$\rho = \frac{P \cdot MW}{RT} \quad \text{or} \quad \rho_i = \frac{P_i \cdot MW}{RT}$$

Application Example

- Suppose the tires on your car are inflated to 32 psig at 25°C. What is the tire pressure at -10°C? Assume that you are at sea level. Would this make a difference in your answer?

Time Saver!

$$n = \frac{P_1 V}{RT_1} = \frac{P_2 V}{RT_2} \quad \rightarrow \quad P_2/T_2 = P_1/T_1$$

$$P_1 = 32 \text{ psig} + 14.7 \text{ psia} = 46.7 \text{ psia}$$

$$P_2 = P_1(T_2/T_1) = 46.7 \text{ psia} \cdot (263 \text{ K}/298 \text{ K}) = 41.2 \text{ psia}$$

$$41.2 - 14.7 = 26.5 \text{ psig}$$

$$\text{If } P_{\text{atm}} = 12.5, P_2 = 39.3 \text{ psia} = 26.8 \text{ psig}$$

Standard Conditions

- Provide a reference point for reporting gas flows
- Convenient for use in calculations with ideal gas law

SI

$T_s = 0^\circ\text{C} = 273\text{K}$
 $P_s = 1 \text{ atm}$
 $V_s = 0.022415 \text{ m}^3 \text{ (22.415 L)}$
 $n_s = 1 \text{ gmol}$

American Engineering

$T_s = 492^\circ\text{R}$ (i.e., 32°F)
 $P_s = 1 \text{ atm}$
 $V_s = 359 \text{ ft}^3$
 $n_s = 1 \text{ lb-mole}$

Society of Petroleum Engineers (common industrial standard)

$T_s = 60^\circ\text{F}$
 $P_s = 14.7 \text{ psia}$

Gas Flows under Standard Conditions

- SCM**: standard cubic meters (m³ STP)
- SCF**: standard cubic feet (ft³ STP)
- SCFM**: standard cubic feet per minute (ft³/min STP)
- SCMH**: standard cubic meters per hour (m³/hr STP)
- SCFH**: standard cubic feet per hour (ft³/hr STP)
- SCCM**: standard cubic centimeters per minute (cm³/min STP)
- SLPM**: standard liters per minute (lit/min STP)

Gas Flows under Standard Conditions

- **SCM**: standard cubic meters (m³ STP)
- **SCF**: standard cubic feet (ft³ STP)
- **SCFM**: standard cubic feet per minute (ft³/min STP)
- **SCMH**: standard cubic meters per hour (m³/hr STP)
- **SCFH**: standard cubic feet per hour (ft³/hr STP)
- **SCCM**: standard cubic centimeters per minute (cm³/min STP)
- **SLPM**: standard liters per minute (lit/min STP)

Standard Conditions and Ideal Gas Calculations

$$PV = nRT$$

$$P_s \hat{V}_s = RT_s \quad (s = \text{standard state})$$

$$\frac{PV}{P_s \hat{V}_s} = n \frac{T}{T_s}$$

Given standard volume or volumetric flow rate, use ratios to convert to actual volume or volumetric flow rate

Example

- The flow rate of a stream at 285°F and 1.3 atm is measured with an orifice meter. The calibration chart for the meter indicates that the flow is 3.95 x 10⁵ SCFM. Calculate the molar flow rate and the true volumetric flow rate of the stream.

$$\frac{P \dot{V}}{P_s \dot{V}_s} = \frac{\dot{n} T}{\dot{n} T_s}$$



$$\dot{V} = \dot{V}_s \left(\frac{P_s}{P} \right) \left(\frac{T}{T_s} \right) = 3.95 \times 10^5 \text{ SCFM} \left(\frac{1 \text{ atm}}{1.3 \text{ atm}} \right) \left(\frac{745^\circ \text{R}}{492^\circ \text{R}} \right) = 4.60 \times 10^5 \text{ ft}^3 / \text{min}$$

Gas Mixtures



- **Partial pressure** of component A

$$P_A = y_A P_{\text{tot}}$$

- Dalton's Law

total P = sum of partial pressures

Example: At sea level, what is the partial pressure of O₂?

$$p_{\text{O}_2} = y_{\text{O}_2} P_{\text{tot}} = 0.21 * 1.0 \text{ atm} = 0.21 \text{ atm}$$

- Good for both ideal and non-ideal gases!

Ideal Gas Mixtures

- Amagat's Law
partial volumes add up to total volume

$$V_A + V_B + \dots = V_{\text{tot}}$$

- Volume fraction = mole fraction
percent by volume = mole percent

$$V_A = y_A V_{\text{tot}}$$

Good only for ideal gases!