

Chapter 5

Gases

Section 5.1

Pressure



Properties of gases

- Uniformly fill any container and take its shape.
- Easily compressed.
- Mixes completely with any other gas.
- Exerts pressure on its surroundings.

Section 5.1

Pressure



Measurement of Pressure:

- The atmospheric pressures is measured by barometer.
- The pressure of a gas confined in a container is measured by manometer. (car tire, home gas cylinder, ...)

Section 5.1

Pressure



Pressure:

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

- SI units = Newton/meter² = 1 Pascal (Pa)
- 1 standard atmosphere = 101.325 KPa ; (101,325 pa)
- 1 standard atmosphere = 1 atm
 - = 1.01325 bar
 - = 760 mm Hg = 760 torr
 - = 14.7 Lb/in² ; (psi: pound per square inch)

Section 5.1

Pressure



Example: Pressure Conversions:

The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

$$(2.5 \text{ atm}) \times \left(\frac{760 \text{ torr}}{1 \text{ atm}} \right) = 1.9 \times 10^3 \text{ torr}$$

$$(2.5 \text{ atm}) \times \left(\frac{101,325 \text{ Pa}}{1 \text{ atm}} \right) = 2.5 \times 10^5 \text{ Pa}$$

Section 5.2

The Gas Laws of Boyle, Charles, and Avogadro



Variables affecting the state of a gas:

- Temperature.
- Pressure
- Volume
- Number of moles

(T, P, V, n)

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Ideal Gas Law

Pressure (P), temperature (T), and number of moles (n) are related to the volume as follows:

- Volume is inversely proportional to pressure, so, $V = k/P$
- Volume is directly proportional to temperature, so, $V = bT$
- Volume is directly proportional to number of moles, so, $V = an$

K, b, and a are proportionality constants. Consequently:

$$V = (kba)(nT/P)$$

The constants (kba) may be combined in one constant R, so:

$$V = \frac{nRT}{P}$$

OR: $PV = nRT$ (Ideal Gas Law)

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- R is called universal gas constant.

$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$, (R has different values depending on the unit of the pressure.)

If certain amount of gas (n) is moved from certain initial state (i) to certain final state (f), then:

$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

At constant pressure:

$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

At constant Temperature:

$$P_i V_i = P_f V_f$$

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Example:

A sample of helium gas occupies 12.4 L at 23 °C and 0.956 atm. What volume will it occupy at pressure of 1.20 atm at the same temperature?

$$V_f = V_i \left(\frac{P_i}{P_f} \right)$$

$$V_f = (V_i)(P_i/P_f) = (12.4 \text{ L})(0.956 \text{ atm.}/1.20 \text{ atm.}) = 9.88 \text{ L}$$

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- Example: [Temperature in all calculations should be in K]

A balloon containing 1.30 L of air at 24.7 °C is placed into a beaker containing liquid nitrogen at -78.5°C. What will the volume of the balloon if the pressure stays constant?

$$K = ^\circ\text{C} + 273$$

$$T_1 = 24.7 + 273 = 297.7 \text{ K}$$

$$T_2 = -78.5^\circ\text{C} + 273 = 194.5 \text{ K}$$

$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

$$V_f = (V_i)(T_f/T_i) = 0.849 \text{ L}$$

Section 5.3

The Ideal Gas Law



Car tire at 23 °C with an internal volume of 25.0 L is filled with air to a total pressure of 3.18 atm. Determine the number of moles of air in the tire.

$$n = PV/RT$$

$$T = 23 + 273 = 296 \text{ K}$$

$$\begin{aligned} n &= (3.18\text{atm})(25.0\text{L})/(0.08206\text{...})(296 \text{ K}) \\ &= 3.27 \text{ mol} \end{aligned}$$

Section 5.3

The Ideal Gas Law



Example:

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25 °C? $PV=nRT$

$$T = 25 + 273 = 298\text{K}$$

$$n = \text{mass/atomic mass} = 5.670 \times 1000 / 4 = 1417.5 \text{ mol}$$

$$P = nRT/V \quad ; \quad R = 0.0821 \text{ L.atm./K.mol.}$$

$$= \dots = 114 \text{ atm}$$

Section 5.3

The Ideal Gas Law



■ Example:

At what temperature (in °C) does 121 mL of CO₂ at 27 °C and 1.05 atm. occupy a volume of 293 mL at a pressure of 1.40 atm.?

Solution:

$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

$$T_f = T_i \frac{P_f V_f}{P_i V_i}$$

$$T_f = \dots\dots = \dots\dots = \mathbf{696 \text{ }^\circ\text{C}}$$

Section 5.4

Gas Stoichiometry



Standard Molar Volume of an Ideal Gas (SMV)

- SMV is the volume of one mole of a gas under STP
- For 1 mole of an ideal gas at 0 °C and 1 atm, the volume of the gas is 22.42 L.

$$V = \frac{nRT}{P} = \frac{(1.000 \text{ mol})(0.08206 \text{ L} \cdot \cancel{\text{atm}}/\text{K} \cdot \text{mol})(\cancel{273.2 \text{ K}})}{1.000 \cancel{\text{ atm}}} = 22.42 \text{ L}$$

- STP = Standard Temperature and Pressure
 - 0° C and 1 atm
 - Therefore, the molar volume is 22.42 L at STP.
 - (T,P,V,n)

Section 5.4

Gas Stoichiometry

Example:

A sample of oxygen gas has a volume of 2.50 L at STP. How many grams of O₂ are present?

$$\text{MM}(\text{O}_2) = 32 \text{ g/mol}$$

$$n = PV/RT$$

$$T = 273 \text{ K} \quad ; \quad P = 1 \text{ atm.} \quad ; \quad R = 0.0821 \text{ L.atm.}$$

$$\text{So, } \dots n = 0.112 \text{ mol,}$$

$$\text{mass} = (\text{MM})(n) = (32\dots)(0.112\dots) = 3.57 \text{ g}$$

$$\text{OR} \quad \text{STP: } 1 \text{ mol} = 22.42 \text{ L}$$

Section 5.4

Gas Stoichiometry



Molar Mass (MM) and Density (d) of a gas

- $PV = nRT$
- $n = \text{mass}/\text{MM}$
- Density (d) = mass/V
- $PV = (\text{mass}/\text{MM})(RT)$
- Rearrange for the MM, so:
- $\text{MM} = (d)(RT/P)$
- Rearrange for the density, So:
- $d = (\text{MM})(P/RT)$
- (P, T, d, MM) (P V T n)

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What is the density of F_2 at STP (in g/L)?

$d = (MM)(P/RT)$, STP (1 atm. *and* 273 K)

$MM(F_2) = 39 \text{ g/mol}$

$$d = 1.70 \text{ g/L}$$

$R = 0.0821 \text{ L.atm/mol.K}$

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(i) What is the volume of a mixture of 5.00 g of H_2 gas and 5.00 g of He gas at STP?

$$V = ? \quad PV = n_t RT$$

(ii) What is the mass of nitrogen gas (N_2) that occupies the same volume under the same conditions (STP)?

Solution: $n = \text{mass}/\text{MM}$

(i) $n(\text{H}_2) = 5.00/2 = 2.50 \text{ mol.}$

$$n(\text{He}) = 5.00/4 = 1.25 \text{ mol.}$$

$$n_t = \dots\dots = 3.75 \text{ mol.}$$

$$V = n_t RT/P = \dots\dots = (3.75)(0.0821\dots)(273 \text{ K})/ 1 \text{ atm.} \dots = 84.05 \text{ L}$$

(ii) $n(\text{N}_2) = n_t = \dots\dots$

$$\text{mass}(\text{N}_2) = (\text{MM})(n_t) = \dots = (3.75 \text{ mol.})(28\dots) = 105 \text{ g}$$

Section 5.4

Gas Stoichiometry

Gas Stoichiometry

Methane gas (CH_4), $V = 2.80\text{L}$, $25\text{ }^\circ\text{C}$, 1.65 atm . reacted with oxygen gas (O_2), 35.0L , $31\text{ }^\circ\text{C}$, 1.25 atm . To produce CO_2 and water. what is the mass of CO_2 produced? What is the volume of CO_2 produced under 2.5 atm . and $125\text{ }^\circ\text{C}$?



$$n(\text{mole}): \quad 0.189 \quad 1.75 \quad ?$$

$$n = PV/RT$$

$$n(\text{CH}_4) = (1.65\text{ atm})(2.8\text{L}) / (0.0821\text{Latm/mol.K})(298\text{K}) = 0.189\text{ mol.}$$

$$n(\text{O}_2) = \dots\dots = 1.75\text{ mol.}$$

\therefore CH_4 is the limiting reactant.

NOW: All calculations are based on the L.R.

Section 5.4

Gas Stoichiometry



Moles(CO_2) = moles of CH_4 (L.R) = 0.189 mol.

Mass of CO_2 produced = moles x MM

$$= 0.189 \text{ mol.} \times 44 \text{ g/mol.} = 8.3\text{g}$$

$PV = nRT$

$V(\text{CO}_2) = nRT/P$

$$= (0.189)(0.0821\dots)(398 \text{ K})/2.5 \text{ atm} = 2.47 \text{ L}$$

Exercise:

What is the volume of CO_2 at STP?

Section 5.5

Dalton's Law of Partial Pressures

- For a mixture of gases 1, 2, 3, ... in a container,

$$P_{Total} = P_1 + P_2 + P_3 + \dots$$

3.0 L $PV=n_tRT$ O₂

- Volume of gas mixture is V, and contains H₂, N₂, He = 10.0L
- $P(\text{mixture}) = P(\text{H}_2) + P(\text{N}_2) + P(\text{He})$
- The total pressure exerted is the sum of the pressures that each gas would exert if it were alone under the same conditions of volume, temperature and number of moles.

Example:

A gas mixture of 10 g of each of H₂, N₂ and He under 25 °C has a volume of 15.0 L.

- What is the pressure of the gas mixture?
- What is the partial pressure of (N₂) gas in the mixture?

Section 5.5

Dalton's Law of Partial Pressures



$$P = \frac{n_t RT}{V}, \quad T = 298 \text{ K}, V = 15.0 \text{ L}, R = 0.0821 \text{ L.atm./mol.K}$$

- $n_t = n(\text{H}_2) + n(\text{N}_2) + n(\text{He})$
- $n(\text{H}_2) = \text{mass/MM} = 10.0\text{g}/2 \dots = 5.0 \text{ mol.}$
- $n(\text{N}_2) = 10.0\text{g}/28 \dots = 0.357 \text{ mol.}; \quad n(\text{He}) = 10.0/4.0 = 2.5 \text{ mol.}$
- $n_t = PV/RT = \dots = n(\text{H}_2) + n(\text{N}_2) + n(\text{He}) = \dots = 7.86 \text{ mol.}$

$$\begin{aligned} \text{(i)} \quad P &= n_t RT/V = (7.86 \text{ mole})(0.082 \dots)(298 \text{ K})/15.0 \text{ L} \\ &= 12.82 \text{ atm.} \end{aligned}$$

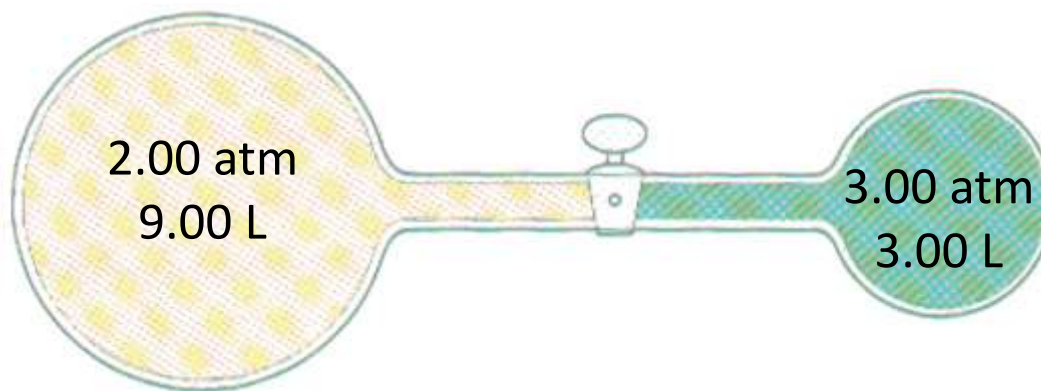
$$\begin{aligned} \text{(ii)} \quad P(\text{N}_2) &= n(\text{N}_2)RT/V = (0.357 \text{ mol.})(0.082 \dots)(298 \text{ K})/15.0 \text{ L} \\ &= 0.582 \text{ atm.} \end{aligned}$$

Section 5.5

Dalton's Law of Partial Pressures

Consider the following apparatus containing helium in both sides at 45 °C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas, if there is no change in temperature?



Section 5.5

Dalton's Law of Partial Pressures

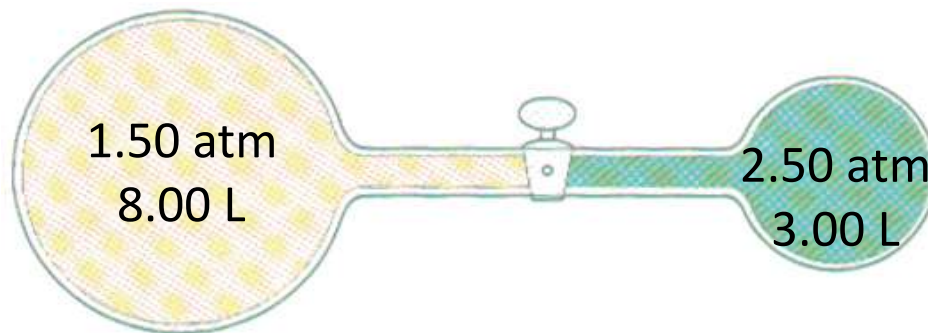


- $n_{\text{left}} = PV/RT = (2)(9)/(0.0821\dots)(318\text{K}) = 0.689 \text{ mol.}$
- $n_{\text{right}} = PV/RT = (3)(3)/(0.0821\dots)(318\text{K}) = 0.345 \text{ mol.}$
- $n_{\text{total}} = 0.689 + 0.345 = 1.034 \text{ mol.}$
- New volume after mixing, $V_{\text{total}} = 9 + 3 = 12 \text{ L}$
- P (after opening the valve) = $n_t RT/V_t$
= $(1.034\text{mol})(0.0821 \dots)(318 \text{ K})/12 \text{ L}$
= **2.25 atm.**

Section 5.5

Dalton's Law of Partial Pressures

Consider the apparatus below. The left-hand side contains O_2 and the right-hand side contains N_2 . $T = 300$ K. Calculate the partial pressures and the pressure of the gas mixture after the valve is opened?



- $n = PV/RT$; $P_i = n_iRT/V$
- $n(O_2)$, left = ... = 0.487 mol. ; $n(N_2)$, right = ... = 0.304 mol.
- After mixing: $V = 3.0 + 8.0 = 11.0$ L
- After opening the valve:
- $P(O_2) = \dots = 1.09$ atm. ; $P(N_2) = \dots = 0.681$ atm.
- $P = 1.09 + 0.681 = 1.77$ atm.

Section 5.5

Dalton's Law of Partial Pressures



END OF CHAPTER 5