

ninth edition

Chemistry

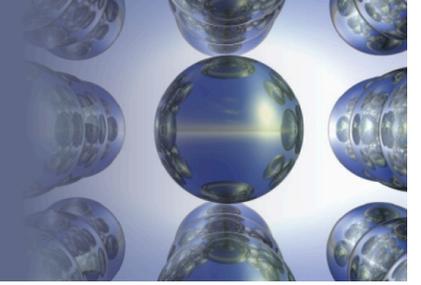
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Chapter 5

Gases

Section 5.1

Pressure

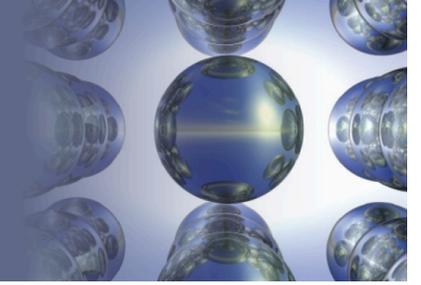


Properties of gases

- Uniformly fill any container and take its shape.
- Easily compressed.
- Mix together completely.
- Exerts pressure on its surroundings.

Section 5.1

Pressure



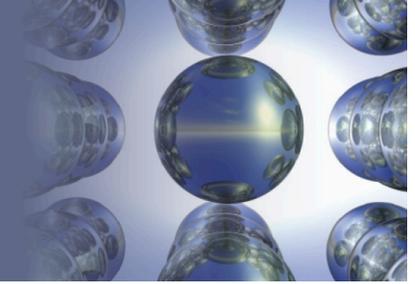
Measurement of Pressure:

There are two types of pressure measurement:

- 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



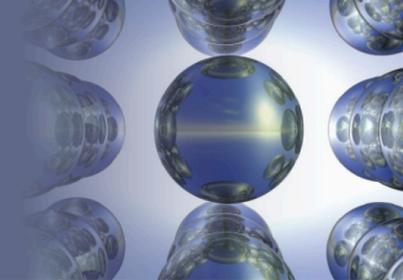
Pressure:

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

- 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:

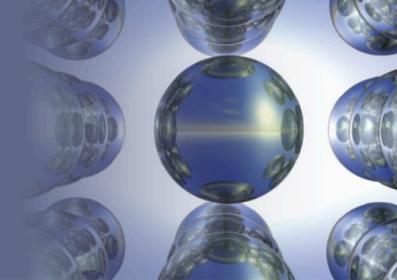
The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr. and pascal.

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

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

Section 5.2

The Gas Laws of Boyle, Charles, and Avogadro



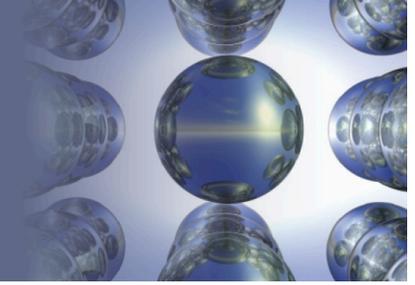
Variables affecting the state of a gas:

- Temperature.
- Pressure
- Volume
- Number of moles

(T, P, V, n)

These variables are related together.

Chapter 5



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:

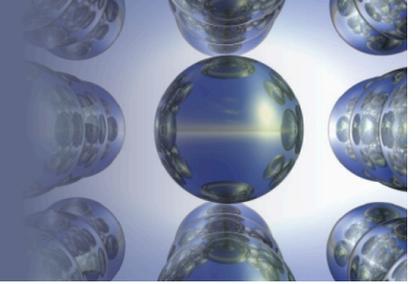
$$V = (kba)(nT/P)$$

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

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

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

Chapter 5

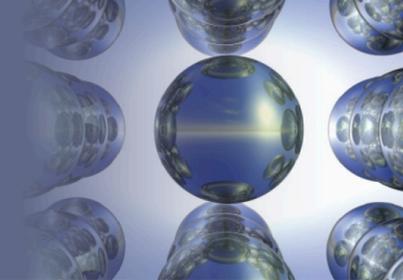


Ideal Gas Law:

- $PV = nRT$
- Independent of the type of the gas.
- Gasses under the same conditions of T, P and V have the same number of moles.
- Gasses under the same conditions of T, P and n have the same volume.
- In the same way . . .

BUT

THEY DIFFER IN THEIR MASSES



The Universal Gas Constant, R:

$$\blacksquare R = \frac{PV}{nT}$$

- There are different values of R depending on the units of P and V. The temperature is always in degrees Kelvin.
- If the P is in atm., and the V is in L, then:
 - $R=0.08206 \text{ L.atm./mol.K}$
- R has different values if the P and V are expressed in different units.

Chapter 5

- State of a system is specified by its T, P and V.
- If certain amount of gas is transferred from an initial state (i) to a final state (f), then the following can be written:

- $$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f} \quad (\text{All } P, V, \text{ and } T \text{ have change})$$

- $$P_i V_i = P_f V_f \quad (\text{Change at constant temperature})$$

- $$\frac{V_i}{T_i} = \frac{V_f}{T_f} \quad (\text{change at constant pressure})$$

Chapter 5

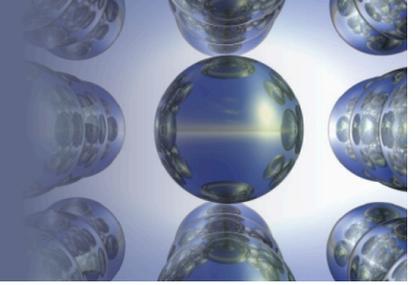
Example:

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?

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

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

Chapter 5



■ 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?

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

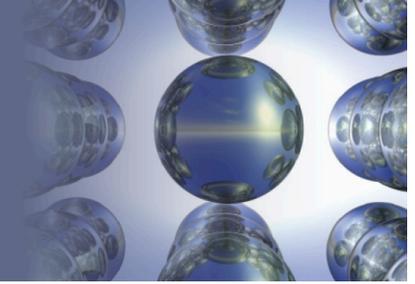
$$T_1 = 24.7 + 273 = 297.7 \text{ K}$$

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

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

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

Chapter 5



- $T_f = T_i (\textit{Pressure Ratio})(\textit{Volume Ratio})$
- $d_f = d_i (\textit{Pressure Ratio})(\textit{Temperature Ratio})$
- $V_f = V_i ()$

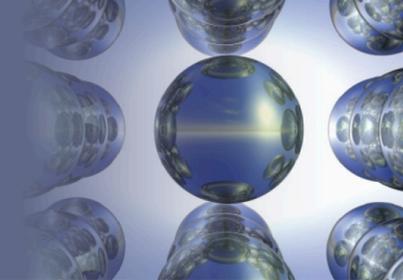
.

$d_i = 1.55$ $T_i = 10$ $P_i = 1.2$ $T_f = 25$ $P_f = 1.5$ $d_f = ?$

You may write any equation you need depending on the problem that you have.

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.

$$n = PV/RT$$

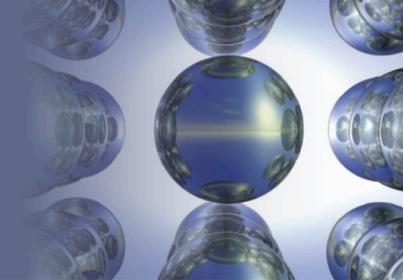
$$T = 23 + 273 = 296 \text{ K}$$

$$n = (3.18\text{atm})(25.0\text{L})/(0.08206\dots)(296 \text{ K})$$

$$= 3.27 \text{ mol}$$

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? $PV=nRT$

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

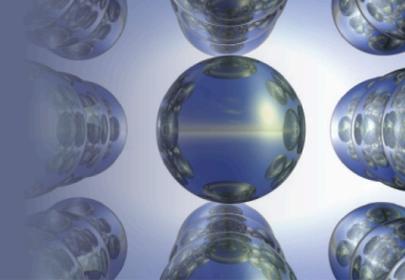
$$n = \text{mass/atomic mass} = 5.670 \times 1000 / 4 = 1417.5 \text{ mol}$$

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

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

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:

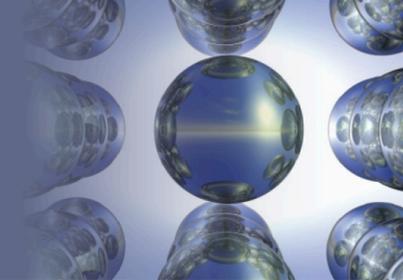
$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

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

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

Section 5.4

Gas Stoichiometry



Standard Molar Volume of an Ideal Gas (SMV)

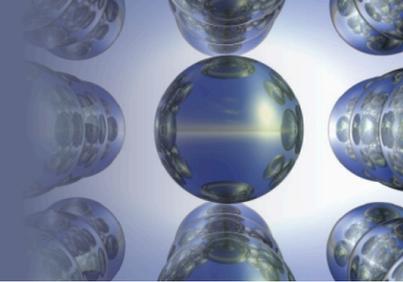
- SMV is the volume of one mole of a gas under STP
- For 1 mole of an ideal gas at 0 °C and 1 atm, the volume of the gas is 22.42 L.

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

- 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?

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

$$n = PV/RT$$

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

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

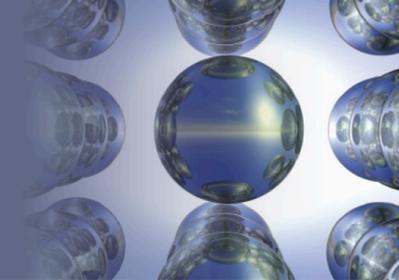
$$\text{mass} = (\text{MM})(n) = (32\text{.....})(0.112\text{...}) = 3.57 \text{ g}$$

OR **STP: 1 mol = 22.42 L**

$$n = 2.5 / 22.42 =$$

Section 5.4

Gas Stoichiometry



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

■ $PV = nRT$

■ $n = \text{mass}/\text{MM}$

■ $\text{Density (d)} = \text{mass}/V$

■ $PV = (\text{mass}/\text{MM})(RT)$

■ *Rearrange for the MM, so:*

■ $\text{MM} = (d)(RT/P)$

■ *Rearrange for the density, So:*

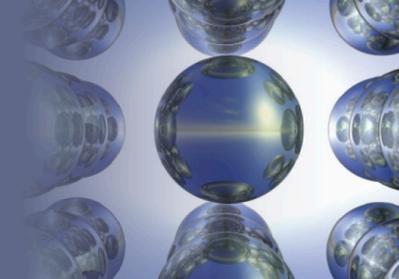
■ $d = (\text{MM})(P/RT)$

■ (P, T, V, n)

(P, T, V mass, MM)

(P, T, d, MM)

Chapter 5



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

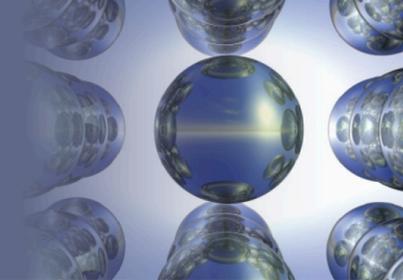
$d = ()$, STP (1 atm. *and* 273 K)

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

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

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

Chapter 5



(i) What is the volume of a mixture of 5.00 g of H₂ gas and 5.00 g of He gas at STP?

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

(ii) What is the mass of nitrogen gas (N₂) that occupies the same volume under the same conditions (STP)?

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

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

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

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

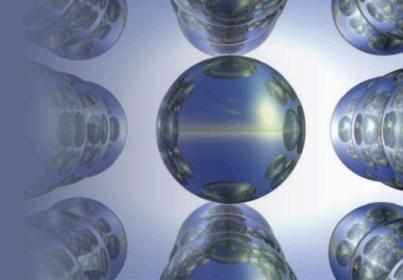
$$V = n_t RT/P = \dots\dots = (3.75)(0.0821\dots)(273 \text{ K})/ 1 \text{ atm. } \dots = 84.05 \text{ L}$$

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

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

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(mole): 0.189 1.75 ?

$$n = PV/RT$$

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

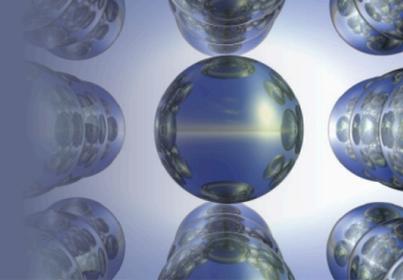
$$n(\text{O}_2) = \dots\dots\dots = 1.75\text{ mol.}$$

\therefore CH_4 is the limiting reactant.

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

Section 5.4

Gas Stoichiometry



$$\text{Moles}(\text{CO}_2) = \text{moles of CH}_4 \text{ (L.R)} = 0.189 \text{ mol.}$$

$$\text{Mass of CO}_2 \text{ produced} = \text{moles} \times \text{MM}$$

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

$$PV = nRT$$

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

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

Exercise:

What is the volume of CO₂ at STP?

Section 5.4

Gas Stoichiometry

Oxygen and nitrogen gasses have the same volume and temperature, but different number of moles.



Oxygen



Pressure
159 mm Hg

+



Nitrogen



Pressure
593 mm Hg

=



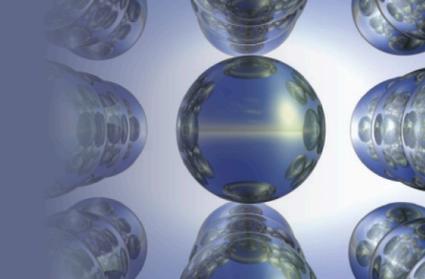
Oxygen + Nitrogen



Pressure
752 mm Hg

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 $PV=n_tRT$ O_2

- Volume of gas mixture is V, and contains H_2 , N_2 , He = 10.0L
- $P(\text{mixture}) = P(H_2) + P(N_2) + P(He)$
- 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.

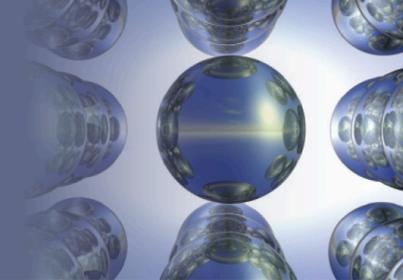
Example:

A gas mixture of 10 g of each of H_2 , N_2 and He under 25 °C has a volume c
15.0 L.

- (i) What is the pressure of the gas mixture?
- (ii) What is the partial pressure of (N_2) gas in the mixture?

Section 5.5

Dalton's Law of Partial Pressures



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

$$\blacksquare n_t = n(\text{H}_2) + n(\text{N}_2) + n(\text{He})$$

$$\blacksquare n(\text{H}_2) = \text{mass/MM} = 10.0\text{g}/2 \dots = 5.0 \text{ mol.}$$

$$\blacksquare n(\text{N}_2) = 10.0\text{g}/28 \dots = 0.357 \text{ mol.}; \quad n(\text{He}) = 10.0/4.0 = 2.5 \text{ mol.}$$

$$\blacksquare n_t = PV/RT = \dots = n(\text{H}_2) + n(\text{N}_2) + n(\text{He}) = \dots = 7.86 \text{ mol.}$$

$$(i) P = n_t RT/V = (7.86 \text{ mole})(0.082 \dots)(298 \text{ K})/15.0 \text{ L}$$

$$= 12.82 \text{ atm.}$$

$$(ii) P(\text{N}_2) = n(\text{N}_2)RT/V = (0.357 \text{ mol.})(0.082 \dots)(298 \text{ K})/15.0 \text{ L}$$

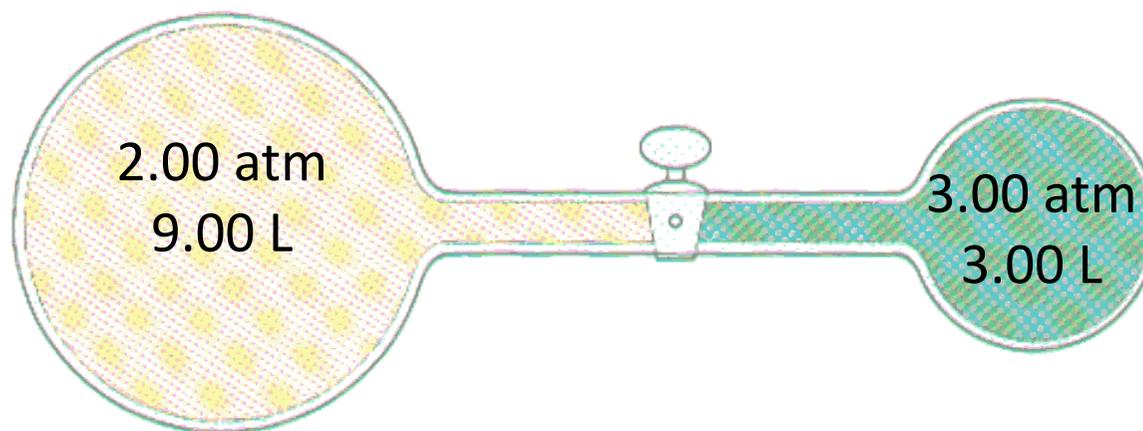
$$= 0.582 \text{ atm.}$$

Section 5.5

Dalton's Law of Partial Pressures

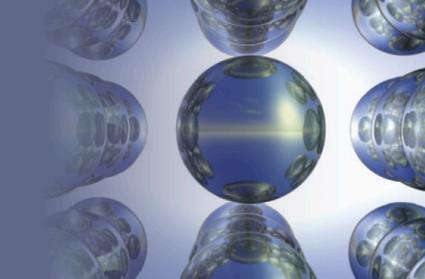
Consider the following apparatus containing helium in both sides at 45 °C. Initially the valve is closed.

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



Section 5.5

Dalton's Law of Partial Pressures

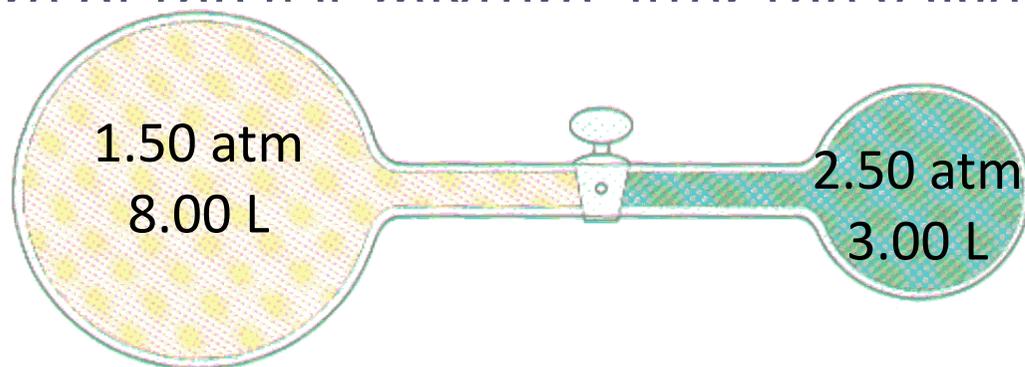


- $n_{\text{left}} = PV/RT = (2)(9)/(0.0821\dots)(318\text{K}) = 0.689 \text{ mol.}$
- $n_{\text{right}} = PV/RT = (3)(3)/(0.0821\dots)(318\text{K}) = 0.345 \text{ mol.}$
- $n_{\text{total}} = 0.689 + 0.345 = 1.034 \text{ mol.}$
- New volume after mixing, $V_{\text{total}} = 9 + 3 = 12 \text{ L}$
- P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

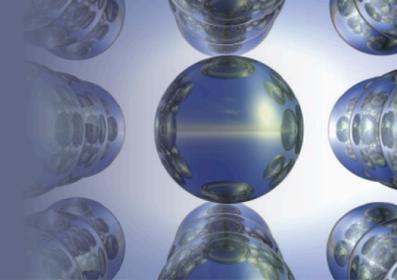
Consider the apparatus below. The left-hand side contains O_2 and the right-hand side contains N_2 . $T = 300$ K. Calculate the partial pressures and the pressure of the gas mixture after the valve is opened?



- $n = PV/RT$; $P_i = n_iRT/V$
- $n(O_2)$, 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