CHEM1011 LECTURE 6

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LEARNING OUTCOMES

At the end this lecture you should also be able to:

- ❑ Describe the properties which distinguish gases from other states of matter.
- ❑ Calculate properties of gases and gas mixtures using the ideal gas equation including applying partial pressures.
- ❑ Calculate rates of effusion and diffusion of gases (Graham's Law).

HOMEWORK 1

(From worked example 6.1) what would the pressure be if the tank was stored in a hot shed where the temperature reached 42°C?

$P = nRT / V$

$= (5.52 \times 10^3 \text{ mol} \times 8.314 \text{ L kPa K}^{-1} \text{ mol}^{-1} \times 315.15 \text{ K}) / 1000 \text{ L}$

$= 1.45 \times 10^4 \text{ kPa or } 14.5 \text{ MPa}$

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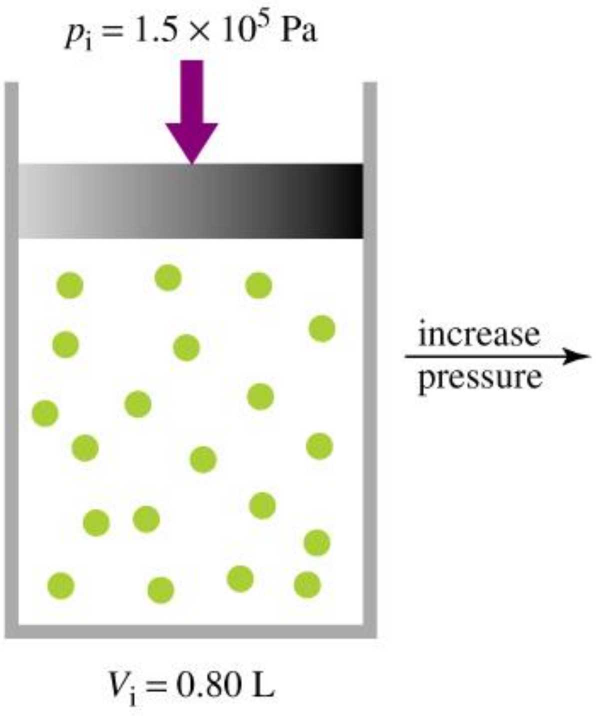
HOMEWORK 2

A sample of helium gas is held at constant temperature inside a cylinder with a volume of 0.80 L when a piston exerts a pressure of 1.5×10^5 Pa. If the external pressure on the piston is increased to 2.1×10^5 Pa, what will the new volume be?



n and T are constant

$P_i \times V_i = P_f \times V_f$

Rearrange for $V_f = (P_i \times V_i) / P_f$

$= 0.57$ L

GASES

The defining characteristic of gases is the pressure they exert.

Pressure comes from the collision of molecules exerting force of an area….doesn't matter what the molecules are...just how many molecules!

The pressure (p) exerted by a gas is dependent on:

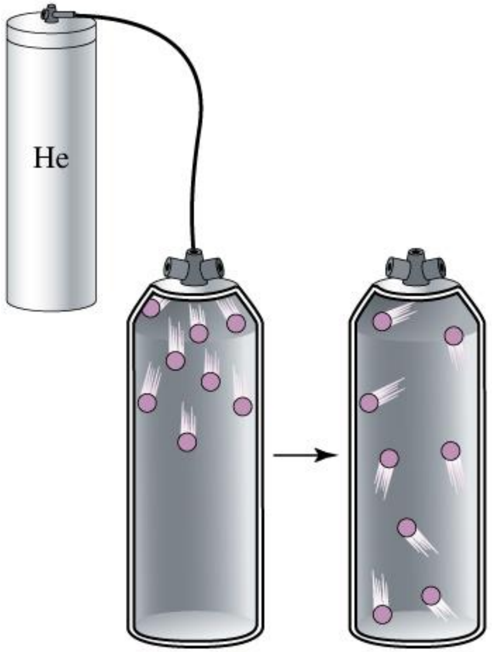
- The amount of gas present (n – number of moles)
- The volume in which it is contained (V)
- Temperature (T)

$$\boxed{PV = nRT}$$

GAS MIXTURES

All constituents of an ideal gas, whether atoms or molecules, act **independently.** Gas mixtures (such as air) follow the same rules.

Gas behaviour depends on the **number of gas atoms or molecules** but not their identity.



(a) (b)

Adding 0.1 mol He gas to an evacuated cylinder and the atoms will quickly distribute uniformly throughout. Adding more He would have the same effect.

GAS MIXTURES

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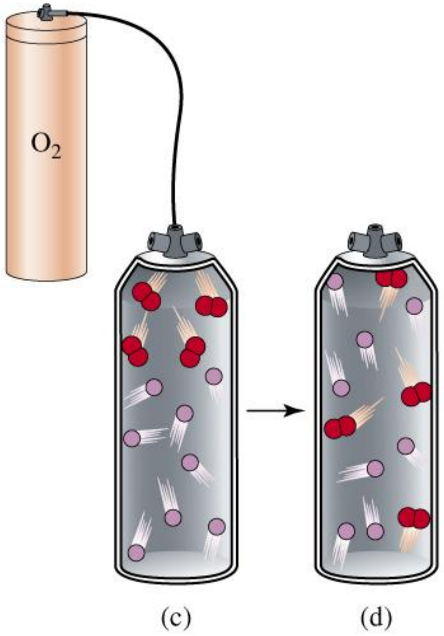
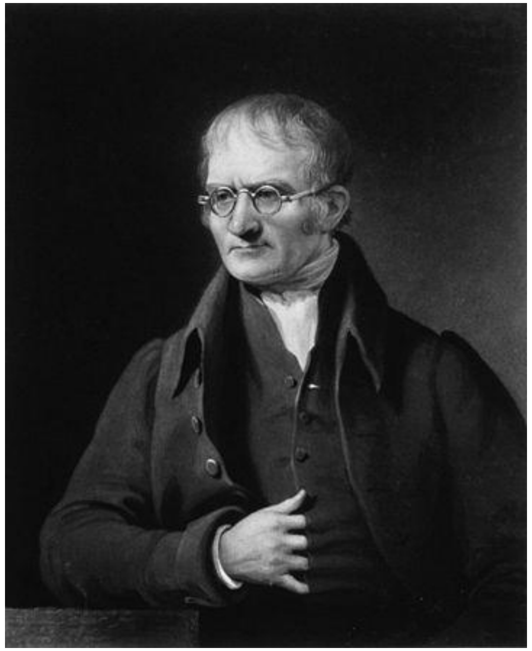


Adding 0.1 mol O_2 gas to the previous cylinder and once again the atoms will quickly distribute uniformly throughout. *The molecules move about independently of the He atoms, causing the gases to mix uniformly.*

DALTON'S LAW OF PARTIAL PRESSURES



By Charles Turner after James Lonsdale, 1834
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"In a mixture of gases the **total pressure exerted is the sum of the partial pressures** that each gas would exert if it alone where present under the same conditions."

In a mixture of un–reacting gases, the total pressure is the sum of the partial pressures of the individual gases:

$$p_{\text{total}} = p_1 + p_2 + p_3 + \cdots + p_n$$

John Dalton FRS (6 September 1766 – 27 July 1844) was an English chemist, physicist, and meteorologist. He is best known for proposing the modern atomic theory and for his research into colour blindness, sometimes referred to as Daltonism in his honour.

EXAMPLE

e.g., adding hydrogen gas to a fixed volume tank containing nitrogen gas at a certain pressure.

Each gas behaves independently, hence:

$$P_{N_2} = \frac{n_{N_2}RT}{V} \quad \text{and} \quad P_{H_2} = \frac{n_{H_2}RT}{V}$$

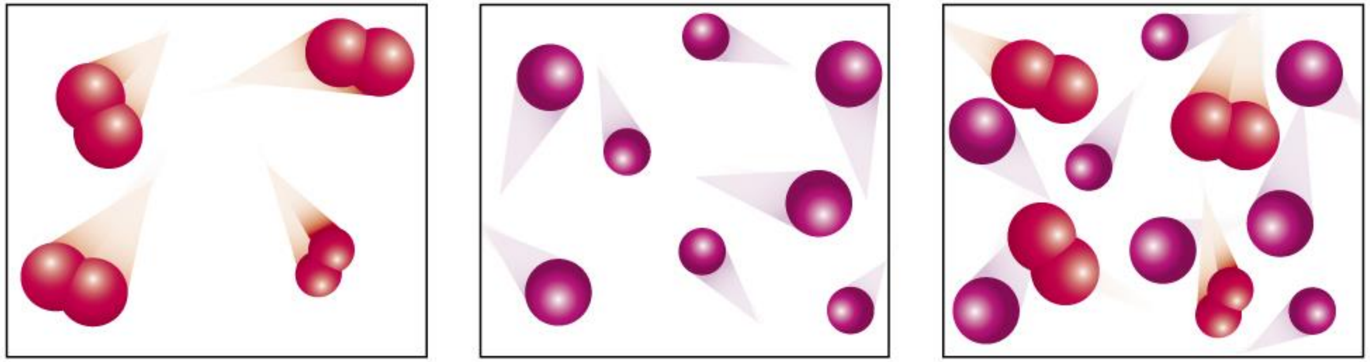
At same volume V and T, the partial pressure of each gas depends on its amount:

$$P_{\text{total}} = P_{N_2} + P_{H_2} = \frac{n_{N_2}RT}{V} + \frac{n_{H_2}RT}{V} = \frac{n_{\text{total}}RT}{V}$$

Note: $n_{\text{total}} = n_{\mathrm{N_2}} + n_{\mathrm{H_2}}$

DALTON'S LAW OF PARTIAL PRESSURES

What is the total pressure if these two gases were combined into the same 20 L container?



20.0 L at 273 K	20.0 L at 273 K	20.0 L at 273 K
0.100 mol O_2	0.200 mol He	0.300 mol gas
$p_{O_2} = 1.13 \times 10^4$ Pa	$p_{He} = 2.27 \times 10^4$ Pa	$p_{O_2} = 1.13 \times 10^4$ Pa
		$p_{He} = 2.27 \times 10^4$ Pa
		$p_{total} = \boxed{}$

Consider a gas cylinder to which you have added a mixture of gases. You added 5 atm of He, 1 atm of Ar and 3 atm of N_2 what is the total pressure of the gas cylinder?

- A Not enough information given
- B 5 atm
- C 9 atm ✓
- D 1 atm

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YOU TRY

Divers must use special gas mixtures in their tanks, rather than compressed air, to avoid N_2 dissolving into the bloodstream : a condition know as “the bends.”

A typical gas cylinder used for such depths contains:
51.2 g of O_2 and 326.4 g of He and has a volume of 10.0L.

What is the partial pressure (in atm) of each gas at 20.00°C, and what is the total pressure in the cylinder at this temperature?

Mole Fractions and partial pressures

Each component in a mixture contributes a fraction of the total number of moles in the mixture, the **mole fraction** (***X***) of that component. e.g., in a N_2/H_2 mixture:

$$\boxed{X_{N_2} = \frac{n_{N_2}}{n_{\text{total}}} = \frac{n_{N_2}}{n_{N_2} + n_{H_2}}}$$

sum of mole fractions of all components in mixture = 1:

$$\begin{aligned} P_{\text{total}} &= P_{N_2} + P_{H_2} \\ &= (X_{N_2} ´ P_{\text{total}}) + (X_{H_2} ´ P_{\text{total}}) \\ &= 1 ´ P_{\text{total}} \end{aligned}$$

The partial pressure of a component in a gas mixture is its mole fraction multiplied by the total pressure

MOLE FRACTION EXERCISE

What are the mole fractions of each gas in air, that is a mixture of:

1.56 atm N_2, 0.42 atm O_2 and 0.02 atm Ar?

A $X_{N_2} = 1.56$, $X_{O_2} = 0.42$, $X_{Ar} = 0.02$

B $X_{N_2} = 0.78$, $X_{O_2} = 0.21$, $X_{Ar} = 0.01$

C $X_{N_2} = 1$, $X_{O_2} = 0.27$, $X_{Ar} = 0.013$

D No idea!

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GAS STOICHIOMETRY – BLACKMAN 6.6

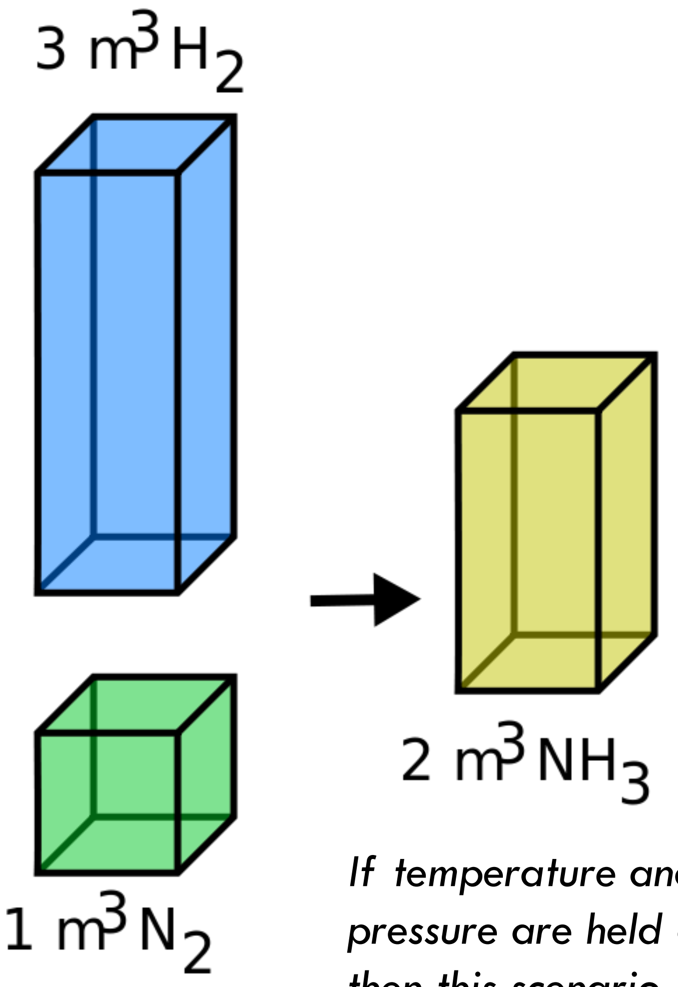
$N_2 + 3\,H_2 \rightarrow 2\,NH_3$

The principles of stoichiometry apply equally to solids, liquids and gases

No matter what phase substances are in, their chemical behaviour can be described in molecular terms

Stoichiometric calculations always requires amounts to be in moles

- **For gases, amounts in moles are usually calculated from the ideal gas equation and thus relatable to pressures and volumes**



If temperature and pressure are held constant then this scenario is true

IDEAL GAS LAW AND REACTION STOICHIOMETRY

Substance	Relationship	Equation
pure liquid or solid	$\text{amount (mol)} = \dfrac{\text{mass (g)}}{\text{molar mass (g mol}^{-1}\text{)}}$	$n = \dfrac{m}{M}$
solution	$\text{amount (mol)} = \text{concentration (mol L}^{-1}\text{)} \times \text{volume (L)}$	$n = cV$
gas	$\text{amount (mol)} = \dfrac{\text{pressure (Pa)} \times \text{volume (m}^3\text{)}}{\text{constant (J mol}^{-1}\text{ K}^{-1}\text{)} \times \text{temperature (K)}}$	$\boxed{n = \dfrac{pV}{RT}}$

Moles and pressure are proportional to each other, therefore you can use stoichiometry to predict resultant partial pressures of products and reactants in the same way as you do for moles!

PARTIAL PRESSURE AND GAS STOICHIOMETRY EXAMPLE (HARDER):

Hydrogen gas at 1200 torr pressure is in a constant volume, constant temperature container, and nitrogen gas is introduced until the total pressure is 2100 torr.

The formation of ammonia is started by adding a catalyst, the whole reaction taking place at constant temperature.

Calculate the partial pressure of (i) hydrogen, and (ii) ammonia, in the container when the partial pressure of nitrogen is 650 torr.

ANSWER:

At the start, before reaction, P_{H2} = 1200 torr; P_{total} = 2100 torr

Dalton's Law => $P_{total} = P_{N2} + P_{H2}$ => P_{N2} = 2100 – 1200 = 900 torr

Reaction starts – both N_2 and H_2 are consumed

Write out a balanced equation:

$N_2 + 3\,H_2 \rightarrow 2\,NH_3$

- **so 1 mol of N_2 reacts with 3 moles H_2**
- ***and* 1 mol of N_2 produces 2 moles NH_3**

Remember that partial pressure of gas is directly proportional to number of moles (from Dalton's Law)

So for every one unit of pressure of N_2 consumed, 3 units of pressure of H_2 are used and 2 units of pressure of NH_3 are made.

N_2 at start = 900 torr; N_2 at end = 650 torr => N_2 used = 900 – 650 = 250 torr

So, H_2 used = 3 * 250 = 750 torr; so (i) P_{H2} remaining = 1200 – 750 = **450 torr**

and (ii), P_{NH3} produced = 2 * 250 = **500 torr**

GAS MIXTURES – MEASURES OF CONCENTRATION

- When referring to lower concentrations in a gas mixture, scientists use parts per million (ppm) or parts per billion (ppb)
- Mole fractions is moles per mole
- ppm is moles per million moles
- ppb is moles per billion moles
- 1 ppm is a mole fraction of 10^{-6}
- 1 ppb is a mole fraction of 10^{-9}