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Chemistry
Teach Yourself Series
Topic 6: Gases

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Gases

Gases are as important to chemistry as are solids and solutions. They are just as important to us since we need to breathe! Therefore the properties of gases are studied in detail. They behave in their own unique way. The amount of a gas present is calculated in a very different fashion to that of a solid. The safety issues associated with gases are also very different. The fact that most gases are colourless adds to the challenge of understanding them.

Behaviour of gas particles

As it appears in Unit 2

The particles in a solid and a liquid interact with each other because they are close to each other.
Gas particles are much further apart. Therefore they don't interact with each other and not many fit into a container under normal circumstances.

Gas container

The **particles** in this container are **not stationary**. They are flying around the container at high speeds, **colliding** with each other and the sides of the container.

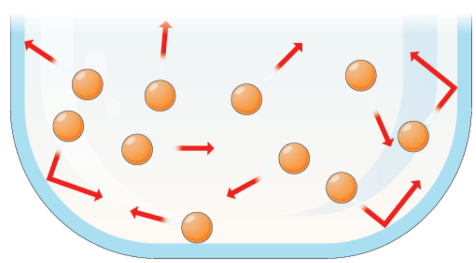
Kinetic Molecular Theory

Kinetic = moving.

- Gases are made of tiny, individual particles. These particles are a long way apart.
- The volume of the particles themselves is negligible compared to the volume of the container.
- Gas particles move rapidly. They move in straight lines, colliding with each other and the container walls
- Collisions are elastic; the particles do not slowly run out of puff!
- The average kinetic energy of particles of different gases are equal at a given temperature
- The average kinetic energy increase as the temperature increases

Balloon

A balloon retains it shape because the fast moving gas particles are colliding with the walls of the balloon. The more particles in the balloon, the more collisions between particles and the walls of the balloon.

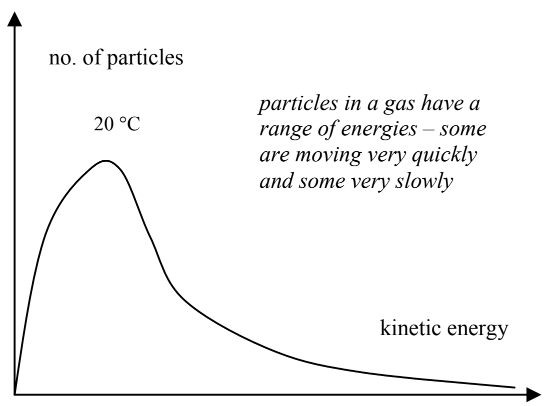


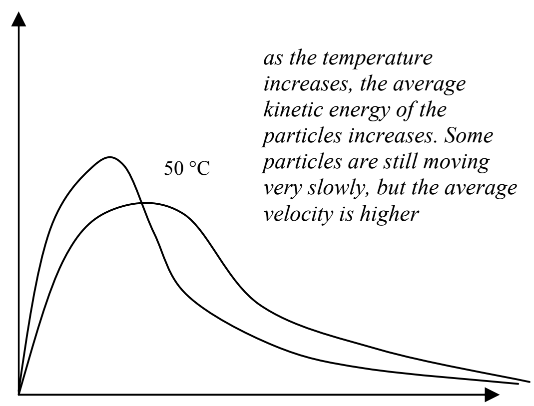
Review Questions

1. Use the Kinetic Molecular theory to explain why
  a. an aerosol can might explode in a fire
  b. we do not feel air particles hitting us
  c. all gas particles in a container are not travelling at the same speed.
  d. Two different gases added to an empty container can mix readily

Kinetic energy of gas particles

At a set temperature, the gas particles have a **range of kinetic energies**. Some particles are moving much faster than others.





If the **temperature of the gas is increased**, the **average kinetic energy** of the particles is **increased**. Not every particle however, is moving faster.
Double graph

To determine the amount of a gas, the pressure, volume and temperature need to be known.

Common gases

As it appears in Unit 2

Oxygen: O_2

Colourless, odorless gas. Non toxic. Essential for combustion and for respiration. Slightly soluble in water. Boiling point -183 °C

Found as: About 21% of air. In Earth's crust as sulfates and carbonates etc.

Laboratory manufacture: $2H_2O_2(g) \rightarrow 2H_2O(l) + O_2(g)$

Industrial manufacture: Fractional distillation of air

Test: Glowing coals reignite in pure oxygen

Nitrogen: N_2

Colourless, odorless gas. Non toxic. Low reactivity.
Boiling point -196 °C. Insoluble in water.

Found as: About 80% of air. In Earth's crust as nitrates and ammonium ions etc.

Industrial manufacture: Fractional distillation of air

Hydrogen: H_2

Colourless, odorless gas. Toxic. Highly flammable. Low solubility

Found in: Water, acids, fatty acids, living things

Laboratory manufacture: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Industrial manufacture: Reforming of methane

Test: Pop test when exposed to a flame

Carbon dioxide: CO_2

Colourless, odorless gas. Toxic. Essential for photosynthesis. Slightly soluble in water. Sublimes at -78 °C

Found as: A greenhouse gas. Product of combustion of fuels

Laboratory manufacture: $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(s) + CO_2(g) + H_2O(l)$

Industrial manufacture: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Test: Turns lime water milky

Combustion equations

These are equations for substances reacting with oxygen. Most organics react with oxygen to **form carbon dioxide and water.**

Example

Write a balanced equation for the reaction between propane and oxygen

Step 1 : Write in reactants and products

$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

Step 2 : Balance carbon and hydrogen

$C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O$

Step 3 : Balance oxygen, using a coefficient of ½ if necessary. Add phases

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

Review Questions

2. Describe one common test that could be used to identify a sample of a gas that is one of hydrogen, oxygen or carbon dioxide.

3. There is more oxygen in the Earth's crust than in the atmosphere. Explain how this can be.

4. What is hydrogen used for?

5. Write a balanced equation for

a. the combustion of ethane

b. the reaction between zinc and hydrochloric acid

c. the reaction between hydrogen and oxygen gases

Gas Units

As it appears in Unit 2

To determine the **amount** of a gas, **the pressure, volume and temperature** need to be known.

Pressure

Pressure is the **force per unit area** exerted by a gas on the container walls.
The more particles, the greater the pressure will be.
The faster the particles are moving the greater the pressure.

$$\textbf{Pressure} = \frac{\textbf{Force}}{\textbf{Area}} = \frac{\textbf{Newton}}{\textbf{m}^2}$$

1 **Pascal** = 1 Newton per square metre

Other units
1 atm = 101 kPa (1 atmosphere = 101000 Pa)
760 mmHg = 101 kPa

Conversion
Convert to kPa
a. 2.4 atm
b. 450 mmHg

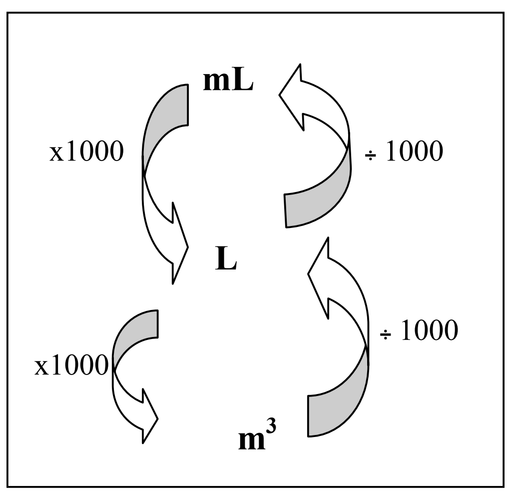
Solution
a. 2.4 x 101 = 242 kPa
b. $\frac{450}{760} \times \frac{101}{1} = 59.8$ kPa

Volume

Litres, symbol L, is a common unit of volume.

Conversion
Convert to litres
a. 0.675 m
b. 24.6 mL

Solution
a. 0.675 x 1000 = 675 L
b. 24.6 ÷1000 = 0.0246L



Review Questions

6. Convert the pressure given to the units stated

- **a.** 4.6 atm to kPa
- **b.** 600 mmHg to kPa
- **c.** 200 kPa to atm
- **d.** 250000 Pa to kPa

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7. Convert the volume to the units stated

- **a.** 46 L to m
- **b.** 0.044 m to L
- **c.** 24.8 mL to L

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Gas Laws

As it appears in Unit 2 and Unit 3

Boyle's Law

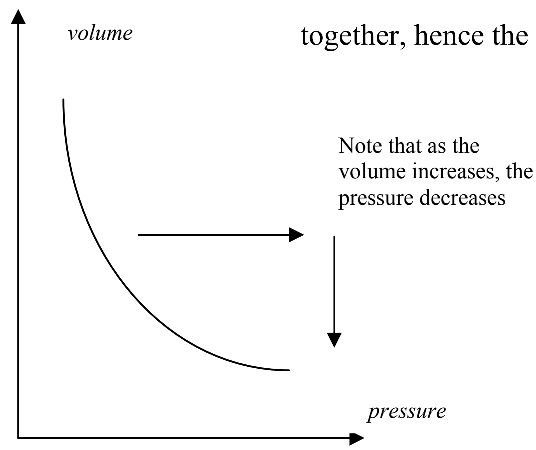
The volume of a gas is inversely proportional to its pressure.
As the volume decreases, the pressure increases.
Pressure times volume gives a constant value

} ***For a given gas at constant temperature***

When the volume is decreased, the particles are closer together, hence the pressure is greater.

$$V \;\alpha\; \frac{1}{P} \quad \text{or} \quad V = \frac{k}{P}$$

$$PV = k \quad \text{or} \quad P_1V_1 = P_2V_2$$



Charles' Law

The volume of a gas is proportional to its temperature
As the temperature increases, so does the volume

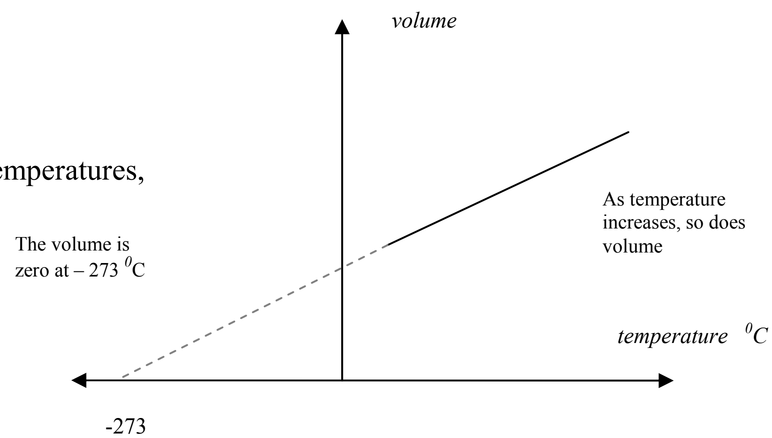
} ***For a given gas at constant pressure***

As the temperature increases, the particles move faster, colliding with the container more vigorously.

$$V \;\alpha\; kT \quad \text{or} \quad V = kT \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Kelvin Temperature Scale

It is not realistic to have negative temperatures, hence scientists use the Kelvin temperature scale.
This starts at **absolute zero** where all substances have no kinetic energy.



Absolute zero = - 273 °C.

Conversion K = °C + 273 or °C = K - 273

Amount of gas

The **volume** of a gas is **proportional to the amount** of gas present
The mole particles, the greater the volume.

} ***For a gas at constant pressure& temp***

V α n or V = kn

Pressure will also be directly proportional to temperature.

General Gas Equation

If	**V α T** **V α n** **V α $\frac{1}{P}$**	**then** $V \alpha \frac{nRT}{P}$ **and** $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ **and PV = nRT** where R = 8.31 and is constant	V: Litres P: kPa n: mol T = K

Example 1

A 0.60 mol sample of helium has a volume of 12 L at 100 ^{0}C. Calculate its pressure.

$$P = \frac{nRT}{V} = \frac{0.6x8.31x373}{12} = 155kPa$$

Notes: Pressure the unknown, so formula expressed in terms of pressure.
Temperature must be converted to Kelvin
R is always 8.31
The fact that it is helium is irrelevant, since 'all gases behave the same'.

Example 2

A 0.84 g sample of hydrogen is added to a vessel at 200 °C. Calculate the volume if the pressure is 220 kPa

$$n(H_2) = \frac{0.84}{2} = 0.42mol$$

$$V = \frac{nRT}{P} = \frac{8.31x0.42x473}{220} = 7.5L$$

Example 3

A sample of nitrogen at 120 °C and 250 kPa, has a volume of 62 L. If the temperature is increased to 150 °C and the pressure to 300 kPa, what will the volume now be?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{250x52}{393} = \frac{300xV_2}{423}$$

V = 47*L*
Note: This version of the formula was used this time because the conditions of the **gas were changed** from one set of values to another.

STP & SLC

As it appears in Unit 2 and Unit 3

The general gas equation can be simplified if the conditions used are very common ones.

STP = Standard temperature and pressure 0 °C and 101 kPa $V = \frac{nRT}{P} = \frac{1x8.31x273}{101} = 22.4L$ At STP ***V* = *n*x22.4**	**SLC** = Standard laboratory conditions 25 °C and 101 kPa $V = \frac{nRT}{P} = \frac{1x8.31x298}{220} = 24.5L$ At SLC ***V* = *n*x24.5**

Example

Calculate the volume of
a. 0.88 mol of hydrogen gas at STP b. 3.4 mol of nitrogen at SLC

Solution

a. At STP ***V*** = *n*x22.4
V = 0.88x22.4
= 19.7 *L*

b. At SLC ***V*** = *n*x24.5
V=3.4x24.5
= 83.3 *L*

Review Questions

8. Calculate the pressure in a 10 L container when 0.88 mol of chlorine gas is stored at 120 ^{0}C.

9. Calculate the mass of helium in a 1.2 L vessel that is at 35 °C and has a pressure of 78 kPa

10. A sample of hydrogen gas is stored at 50 C and a pressure of 76 kPa. Its volume is 5.8 L. If the pressure is increased to 85 kPa and the temperature to 100 °C, what will the volume now be?

11. Calculate the volume of 3.6 mole of argon at

a. STP

b. SLC

Stoichiometry with gases

As it appears in Unit 2 and Unit 3

Example 1
Calculate the volume of hydrogen produced at 80 °C and 1 atm from the reaction of 0.44 g of magnesium in excess hydrochloric acid

Solution
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
0.44 g V=?

$$n(Mg) = \frac{m}{M} = \frac{0.44}{24.3} = 0.018mol$$

$n(H_2) = n(Mg) = 0.018mol$

$$V = \frac{nRT}{P} = \frac{0.018x8.31x353}{101} = 0.53L$$

Example 2
A 12 L sample of methane is burnt in oxygen. If temperature and pressure are held constant, what volumes of carbon dioxide and steam are produced?

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
12 L 24 L 12 L 24 L

If conditions are held constant, there is no need to convert to mole, since all gases behave the same.

Did you know?
Methane, CH_4 is an example of a gas that causes greenhouse issues.

When coal burns, the sulfur it contains will form sulfur dioxide as a pollutant.
$S(s) + O_2(g) \rightarrow SO_2(g)$

Engines can cause nitrogen and oxygen to combine to form pollutant oxides of nitrogen
$N_2(g) + O_2(g) \rightarrow 2NO(g)$

Oxygen has another allotrope, ozone, O_3.

Review Questions

12. Calculate the volume of carbon dioxide that can be produced from 5.0 g of $CaCO_3$. The $CaCO_3$ has been heated to 150 °C and the pressure is 150 kPa.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

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13. 10 L of ethane is reacted with 100 L of gas. What volume of oxygen gas will remain at the end if the temperature and pressure are held constant?

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$$

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Solutions to Review Questions

1. **a**. The increase in temperature will increase the average kinetic energy of the particles. They will collide with the walls of the container harder and harder. If the temperature is high enough, the particles will break through the container wall.

b. The particles are moving rapidly but they have a very low mass.

c. The particles are colliding frequently. They have different velocities.

d. The density of a gas is low. The particles are a long way apart so can pass through each other easily.

2. Use of a lit match. It will pop in hydrogen, burn in oxygen and be extinguished in carbon dioxide.

3. The density of a gas is low so the mass of oxygen in the atmosphere is low. There is more oxygen in the silicates, carbonates and sulfates in the Earth's crust.

4. Fuel, manufacture of other chemicals.

5. Write a balanced equation for

a. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

b. $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

c. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

6. Convert the pressure given to the units stated

a. 4.6 x 101 = 465 *kPa*

b. 600 x 760/101 = 80 *kPa*

c. 200 /101 = 1.98 *atm*

d. 250 *kPa*

7. Convert the volume to the units stated

a. 46/1000 = 0.046 m^3

b. 0.044 x 1000 = 44 *L*

c. 24.8/1000 = 0.0248 *L*

8. Calculate the pressure in a 10 L container when 0.88 mol of chlorine gas is stored at 120 ^{0}C.

$$P = \frac{nRT}{V} = \frac{0.88x8.31x393}{10} = 287kPa$$

9.

$$n = \frac{PV}{RT} = \frac{78x1.2}{8.31x303} = 0.03717mol$$

$$nxMr = 0.03717x4 = 0.15g$$

10.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{76x5.8}{323} = \frac{85xV_2}{373}$$

$$V_2 = 6.0L\ (2\ sf)$$

11. Calculate the volume of 3.6 mole of argon at

a. STP

V = 22.5 x 3.6

= 81L

b. SLC

V = 24.5 x 3.6

= 88.2 L

12. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

$$n = \frac{5}{40+12+48}$$

= 0.05mol

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

$$V = \frac{0.05 \times 8.31 \times 423}{150}$$

$$V = 1.17L$$

13. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

10L $\quad \frac{7}{2}x10 = 35L$

100 – 35 = 65L remain