

1.23 Gas Calculations

Gas calculations at A-level are done in two different ways although both link the volumes of a gas to the amount in moles of the gas. The same amount in moles of any gas will have the same volume under the same conditions of temperature and pressure.

Molar Gas Volume (OCR +EDEXCEL only)

The simplest way of working out the volume of gas is using the molar gas volume of a gas. This works on the principle that 1 mole of any gas will have the same volume under the same conditions of temperature and pressure. Most often this is given as 24dm^3 which is the volume of a gas at room pressure (100kPa) and room temperature 25°C . Different temperatures and pressures will have different molar gas volumes.

$$\text{Gas volume (dm}^3\text{)} = \text{amount} \times 24$$

This equation gives the volume of a gas at room pressure (100kPa) and room temperature 25°C .

Ideal Gas Equation

The ideal gas equation is a slightly more difficult way of working out a gas volume. It can calculate the volume for any temperature and pressure though so is a more useful method.

More detail is given on page 2 about how the ideal gas equation is derived and its limitations.

The biggest problems students have with this equation is choosing and converting to the correct units, so pay close attention to the units.

$$PV = nRT$$

Unit of pressure (P): Pa
Unit of volume (V): m^3
Unit of temperature (T): K
n = moles
R = $8.31 \text{ JK}^{-1}\text{mol}^{-1}$

Converting temperature

$$^\circ\text{C} \rightarrow \text{K add } 273$$

Example 1: Calculate the mass of Cl_2 gas that has a pressure of 100 kPa, temperature 20°C , volume 500 cm^3 . ($R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$)

$$\begin{aligned} \text{moles} &= PV/RT && \leftarrow \begin{array}{l} 100 \text{ kPa} = 100\,000 \text{ Pa} \\ 20^\circ\text{C} = 20 + 273 = 293\text{K} \\ 500 \text{ cm}^3 = 0.0005 \text{ m}^3 \end{array} \\ &= 100\,000 \times 0.0005 / (8.31 \times 293) \\ &= 0.0205 \text{ mol} \end{aligned}$$

$$\begin{aligned} \text{Mass} &= \text{moles} \times M_r \\ &= 0.0205 \times (35.5 \times 2) \\ &= 1.46 \text{ g} \end{aligned}$$

Example 2: 0.15g of a volatile liquid was injected into a sealed gas syringe. The gas syringe was placed in an oven at 70°C at a pressure of 100kPa and a volume of 80cm^3 was measured. Calculate the M_r of the volatile liquid ($R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$)

$$\begin{aligned} \text{moles} &= PV/RT && \leftarrow \begin{array}{l} 100 \text{ kPa} = 100\,000 \text{ Pa} \\ 80 \text{ cm}^3 = 0.00008 \text{ m}^3 \end{array} \\ &= 100\,000 \times 0.00008 / (8.31 \times 343) \\ &= 0.00281 \text{ mol} \end{aligned}$$

$$\begin{aligned} M_r &= \text{mass}/\text{moles} \\ &= 0.15 / 0.00281 \\ &= 53.4 \text{ g mol}^{-1} \end{aligned}$$

Derivation of the Ideal Gas Equation

The ideal gas equation is a combination of three important gas laws.

Boyle's Law - The volume of a fixed amount of gas at a given temperature is inversely proportional to its pressure.

$$V \propto \frac{1}{P} \quad \boxed{P_1V_1 = P_2V_2} \quad \text{at constant } T \text{ \& } n$$

Charles's Law - If a fixed amount of a gas is held at constant pressure, the volume of the gas is directly proportional to the temperature of the gas.

$$\boxed{V \propto T} \quad \text{So for a system that changes } T \text{ and } V -$$
$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}} \quad \text{at constant } P \text{ \& } n$$

Avogadro's Law - Equal volumes of gas at constant temperature and pressure have equal numbers of molecules.

Boyle's Law $\boxed{V \propto \frac{1}{P}}$	Charles's Law $\boxed{V \propto T}$	Avogadro's Law $\boxed{V \propto n}$
Expressed Mathematically –		
$\boxed{V \propto \frac{Tn}{P}}$		
$\boxed{V = R \left(\frac{nT}{P} \right) \Rightarrow PV = nRT}$		

An ideal gas has the following properties:

1. An ideal gas is considered to be a "point mass". A point mass is a particle so small that its mass is very nearly zero. This means an ideal gas particle has almost no volume.
2. There are no attractive or repulsive forces involved during collisions. Also, the kinetic energy of the gas molecules remains constant since the intermolecular forces are lacking.

These assumptions do not actually hold true for many gases. They work best for the Noble gases. Heavier gases and ones with significant intermolecular forces will deviate from ideal gas behaviour.

Changing the conditions of a gas

Questions may involve the same amount of gas under different conditions.

Example 3

40 cm³ of oxygen and 60 cm³ of carbon dioxide, each at 298 K and 100 kPa, were placed into an evacuated flask of volume 0.50 dm³. Calculate the pressure of the gas mixture in the flask at 298 K.

There are two approaches to solving this

1. Work out moles of gas using ideal gas equation then put back into ideal gas equation with new conditions
2. Or combine the equation $n = PV/RT$ as on right

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Can do this as moles of gas do not change

As the temperature is the same we can make the above equation $P_1 V_1 = P_2 V_2$

$$\begin{aligned} P_2 &= P_1 V_1 / V_2 \\ &= 100000 \times 1 \times 10^{-4} / 5 \times 10^{-4} \\ &= 20\,000 \text{ Pa} \end{aligned}$$

Questions using the Ideal Gas Equation

(In all questions use the Ideal Gas Equation and use the gas constant $R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$)

1.1) Calculate the volume of 1.50 mol of carbon dioxide gas at 298 K and 100 kPa.

1.2) A sample of ammonia gas occupied a volume of 0.0278 m^3 at $28 \text{ }^\circ\text{C}$ and 103 kPa. Calculate the number of moles of ammonia in the sample.

1.3) A gas cylinder, of volume $5.00 \times 10^{-3} \text{ m}^3$, contains 348 g of argon gas. Calculate the pressure of the argon gas in the cylinder at a temperature of 20°C

1.4) A 0.153g gaseous sample of ammonia occupied a volume of $2.91 \times 10^{-4} \text{ m}^3$ at a temperature T and a pressure of 100 kPa. Calculate the number of moles of ammonia present and deduce the value of the temperature T .

1.5) A sample of ethanol vapour, $\text{C}_2\text{H}_5\text{OH}$ ($M_r = 46.0$), was maintained at a pressure of 100 kPa and at a temperature of 358 K. Calculate the volume, in cm^3 , that 2.78 g of ethanol vapour would occupy under these conditions.

1.6) When a sample of liquid, **A**, of mass 0.306 g was vaporised, the vapour was found to occupy a volume of $1.76 \times 10^{-4} \text{ m}^3$ at a pressure of 110 kPa and a temperature of $200 \text{ }^\circ\text{C}$. Calculate the number of moles of **A** in the sample and hence deduce the relative molecular mass of **A**.

1.7) Compound **B** is an oxide of sulphur. At 423 K, a gaseous sample of **B**, of mass 0.354 g, occupied a volume of 148 cm^3 at a pressure of 105 kPa. Calculate the number of moles of **B** in the sample, and hence calculate the relative molecular mass of **B**.

1.8) In an experiment, 0.612 mol of hydrogen gas was produced when a sample of magnesium reacted with dilute nitric acid. Calculate the volume that this gas would occupy at 298 K and 98.0 kPa. Include units in your final answer.

Calculations involving masses, solutions and gases

Commonly in questions converting between quantities of substances reacting, we will use more than just mass data. We might have the volume and concentration of a solution, or the volume of a gas. We need to adapt our existing method of reacting masses to include other quantities. Any of the equations below can be used to convert quantities into moles.

1. For pure solids, liquids and gases

$$\text{amount} = \frac{\text{mass}}{\text{MolarMass}}$$

Unit of mass: grams
Unit of amount : mol

2. For Gases

$$\text{Gas Volume (dm}^3\text{)} = \text{amount} \times 24$$

This equation give the volume of a gas at room pressure (1atm) and room temperature 25°C.

Or use the ideal gas equation to work out gas volumes at other temperatures and pressures

$$PV = nRT$$

3. For solutions

$$\text{Concentration} = \frac{\text{amount}}{\text{volume}}$$

Unit of concentration: mol dm⁻³ or M
Unit of Volume: dm³

General method

Step 1:

Use one of the above equations to convert any given quantity into amount in mol
Mass → amount
Volume of gas → amount
Conc and vol of solution → amount

Step 2:

Use balanced equation to convert amount in mol of initial substance into amount in mol of second substance

Step 3

Convert amount, in mol, of second substance into quantity question asked for using relevant equation
e.g. amount, Mr → mass
Amount gas → vol gas
amount, vol solution → conc

Example 4 : Using ideal gas

Calculate the total volume of gas produced in dm³ at 333 K and 100 kPa when 0.651 g of magnesium nitrate is heated.



Step 1: work out moles of magnesium nitrate

$$\begin{aligned}\text{Moles} &= \text{mass} / \text{Mr} \\ &= 0.651 / 148.3 \\ &= 0.00439 \text{ mol}\end{aligned}$$

Step 2: use balanced equation to give moles of gas produced

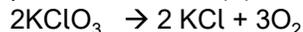
2 moles Mg(NO₃)₂ : 4NO₂(g) + O₂(g) ie 5 moles of gas
So 0.00439 Mg(NO₃)₂ : 0.01098(0.00439 x 5/2) moles gas

Step 3: work out volume of gas

$$\begin{aligned}\text{Volume} &= nRT/P \\ &= (0.01098 \times 8.31 \times 333) / 100000 \\ &= 0.000304\text{m}^3 \\ &= 0.303 \text{ dm}^3\end{aligned}$$

Example 5: Using molar gas volume

Calculate the volume in cm³ of oxygen gas produced from the decomposition of 0.532 g of potassium chlorate(V) at r.t.p



Step 1: work out amount, in mol, of potassium chlorate(V)

$$\begin{aligned}\text{amount} &= \text{mass} / \text{Mr} \\ &= 0.532 / 122.6 \\ &= 0.00434 \text{ mol}\end{aligned}$$

Step 2: use balanced equation to give amount in mol of O₂

2 moles KClO₃ : 3 moles O₂
So 0.00434 KClO₃ : 0.00651 moles O₂

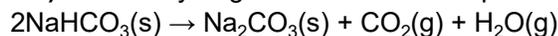
Step 3: work out volume of O₂

$$\begin{aligned}\text{Gas volume (dm}^3\text{)} &= \text{amount} \times 24 \\ &= 0.00651 \times 24 \\ &= 0.156 \text{ dm}^3 \\ &= 156 \text{ cm}^3\end{aligned}$$

Questions combining masses, equations and ideal gas volumes

(In all questions use the Ideal Gas Equation and use the gas constant $R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$)

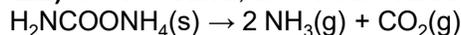
2.1) Sodium hydrogencarbonate decomposes on heating as shown in the equation below.



A sample of NaHCO_3 was heated until completely decomposed. The CO_2 formed in the reaction occupied a volume of 472 cm^3 at $1.00 \times 10^5 \text{ Pa}$ and 298 K .

Calculate the number of moles of CO_2 formed in this decomposition and the mass of NaHCO_3 that was decomposed.

2.2) When heated, ammonium carbamate, $\text{H}_2\text{NCOONH}_4$, decomposes as shown below.

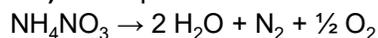


In a closed container, a 6.50 g sample of ammonium carbamate was heated. The solid decomposed completely into ammonia and carbon dioxide at 463 K and 99.7 kPa .

(i) Calculate the number of moles of ammonium carbamate used and the total number of moles of gas produced.

(ii) calculate the total volume of gas produced 463 K and 99.7 kPa . Include units in your answer.

2.3) A sample of ammonium nitrate decomposed on heating as shown in the equation below.



On cooling the resulting gases to 298 K , the volume of nitrogen and oxygen together was found to be 0.0550 m^3 at a pressure of 98.0 kPa .

(i) Calculate the total number of moles of nitrogen and oxygen formed.

(ii) Deduce the number of moles of ammonium nitrate decomposed and hence calculate the mass of ammonium nitrate in the sample.

2.4) An equation representing the thermal decomposition of lead(II) nitrate is shown below.



A sample of lead(II) nitrate was heated until the decomposition was complete. At a temperature of 450 K and a pressure of 100 kPa , the total volume of the gaseous mixture produced was found to be $1.35 \times 10^{-4} \text{ m}^3$.

(i) Calculate the total number of moles of gas produced in this decomposition.

(ii) Deduce the number of moles, and the mass, of NO_2 present in this gaseous mixture.

(iii) Calculate the original mass of the lead nitrate that was decomposed

2.5) Potassium nitrate, KNO_3 , decomposes on strong heating, forming oxygen and solid KNO_2 as the only products.

A 1.00 g sample of KNO_3 was heated strongly until fully decomposed.

(i) Calculate the number of moles of KNO_3 in the 1.00 g sample.

(ii) Calculate the number of molecules of O_2 produced (The Avogadro constant $L = 6.022 \times 10^{23}$)

(iii) Calculate the volume of oxygen gas produced in cm^3 at 298 K and 100 kPa

2.6) UDMH, $(\text{CH}_3)_2\text{N}_2\text{H}_2$, can be used as in combination with dinitrogen tetroxide, N_2O_4 as a fuel in thruster rockets. A thruster rocket contained a total mass of propellant (UDMH and, N_2O_4 , together) of 240 kg mixed in a 1:2 molar ratio. The equation below shows the reaction



(i) Calculate the mass of UDMH in the propellant mixture.

(ii) Calculate the total number of moles of gas produced from the complete reaction of this mass of UDMH with dinitrogen tetroxide,

(iii) Calculate the total volume of product gases formed from the reaction of this mass of UDMH with dinitrogen tetroxide at a temperature of $-9.0 \text{ }^\circ\text{C}$ and a pressure of 550 Pa .

Reacting Volumes of Gas

Equal volumes of any gases measured under the same conditions of temperature and pressure contain equal numbers of molecules (or atoms if the gas is monatomic)

1 mole of any gas at room pressure (1atm) and room temperature 25°C will have the volume of 24dm³

Volumes of gases reacting in a balanced equation can be calculated by simple ratio.

Example 6 500 cm³ of methane is combusted at 1atm and 300K. Calculate the volume of oxygen needed to react and calculate the volume of CO₂ given off under the same conditions.



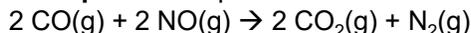
1 mole 2 mole 1 mole

500cm³ 1dm³ 500cm³

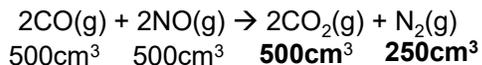


Simply multiply
gas volume x2

Example 7 An important reaction which occurs in the catalytic converter of a car is

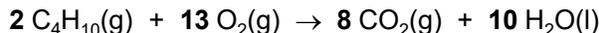


In this reaction, when 500 cm³ of CO reacts with 500 cm³ of NO at 650 °C and at 1 atm. Calculate the **total** volume of gases produced at the same temperature and pressure ?

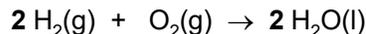


total volume of gases produced = 750cm³

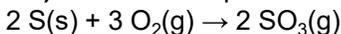
3.1) If 1 dm³ of butane is combusted, what volume of oxygen would be needed and what volume of CO₂ would be given off?



3.2) Calculate the volume of **air** needed for the complete combustion of 500 cm³ of hydrogen? (Assume air contains 20% oxygen)

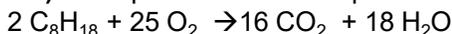


3.3) The overall equation for the reaction between sulfur and oxygen to form sulfur trioxide is shown below.



2 dm³ of O₂(g) reacted completely with excess sulfur. What volume, in dm³, of sulfur trioxide would form?

3.4) The equation for the complete combustion of octane is



The volume of 1 mol of any gas (measured at room temperature and pressure) is 24 dm³. Calculate the volume of oxygen (measured at room temperature and pressure) required for the complete combustion of 5 mol of octane.

3.5) 90 cm³ of methane was reacted with 450 cm³ of oxygen. How much of each gas is present after the combustion and what is the total volume of all gases at the end?



3.6) 20 cm³ of an unknown hydrocarbon needed 120 cm³ of oxygen for complete combustion. 80cm³ of CO₂ was produced. All volumes were measured at rtp. Find the formula of the hydrocarbon.

Answers

- 1.1 $V = 0.0371 \text{ m}^3$
1.2 $n = 1.14 \text{ mol}$
1.3 $P = 4250 \text{ kPa}$
1.4 $T = 389 \text{ K}$
1.5 $V = 1800 \text{ cm}^3$
1.6 $M_r = 62.1$
1.7 $M_r = 80.1$
1.8 $V = 0.0155 \text{ m}^3$
- 2.1 moles $\text{CO}_2 = 0.01906$ mass $\text{NaHCO}_3 = 3.2 \text{ g}$
2.2 (i) moles of ammonium carbamate = 0.083 moles gas = 0.25
(ii) $V = 9.65 \times 10^{-3} \text{ m}^3$
2.3 (i) 2.177 moles total gas
(ii) Moles ammonium nitrate 1.45 mol mass = 116 g
2.4 (i) moles = 0.00361 mol
(ii) Moles $\text{NO}_2 = 0.002888$ Mass $\text{NO}_2 = 0.133 \text{ g}$
(iii) Mass lead nitrate 0.478 g
2.5 (i) $9.89 \times 10^{-3} \text{ mol}$
(ii) 2.98×10^{21}
(ii) 122 cm^3
2.6 (i) mass UDMH 59 kg
(ii) Moles gas 8850 mol
(iii) Volume gas 35300 m^3
- 3.1 $6.5 \text{ dm}^3 \text{ O}_2$ $4 \text{ dm}^3 \text{ CO}_2$
3.2 1.25 dm^3
3.3 1.33 dm^3
3.4 1500 dm^3
3.5 $270 \text{ cm}^3 \text{ O}_2$ $90 \text{ cm}^3 \text{ CO}_2$ total 360 cm^3
3.6 C_4H_8