



Cambridge International AS & A Level

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CHEMISTRY

9701/51

Paper 5 Planning, Analysis and Evaluation

October/November 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

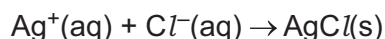
INFORMATION

- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **12** pages. Any blank pages are indicated.



- 1 The concentration of aqueous chloride ions can be found by titration with aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$.



The indicator used is aqueous potassium chromate(VI), $\text{K}_2\text{CrO}_4(\text{aq})$.

As $\text{AgNO}_3(\text{aq})$ is added to aqueous chloride ions, a white precipitate of $\text{AgCl}(\text{s})$ is formed.

When all the chloride ions have reacted, further addition of $\text{AgNO}_3(\text{aq})$ leads to the formation of a red precipitate of silver chromate(VI), $\text{Ag}_2\text{CrO}_4(\text{s})$. The first appearance of the red precipitate shows the end-point of the titration.

A student carries out an experiment to determine the number of molecules of water of crystallisation, x , in hydrated barium chloride, $\text{BaCl}_2 \cdot x\text{H}_2\text{O}(\text{s})$.

(a) The student makes 250.0 cm^3 of $0.0500\text{ mol dm}^{-3}$ $\text{AgNO}_3(\text{aq})$ to use for the titration.

- (i) Calculate the mass of solid silver nitrate, $\text{AgNO}_3(\text{s})$, needed to make 250.0 cm^3 of $0.0500\text{ mol dm}^{-3}$ $\text{AgNO}_3(\text{aq})$.

Give your answer to **two** decimal places.

mass of $\text{AgNO}_3(\text{s}) = \dots\dots\dots\text{g}$ [1]

- (ii) Describe how the student should make 250.0 cm^3 of $0.0500\text{ mol dm}^{-3}$ $\text{AgNO}_3(\text{aq})$ starting from the mass of $\text{AgNO}_3(\text{s})$ calculated in (a)(i) in a 50 cm^3 beaker.

Give the name and size of any key apparatus used.

Write your answer using a series of numbered steps.

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..... [3]



(b) The student uses the following method.

- step 1 Dissolve 1.58 g of $\text{BaCl}_2 \cdot x\text{H}_2\text{O}(\text{s})$ to form 250 cm^3 of aqueous solution. Label this solution **A**.
- step 2 Transfer 20.0 cm^3 of solution **A** into a conical flask.
- step 3 Add aqueous sodium sulfate, $\text{Na}_2\text{SO}_4(\text{aq})$, to the flask and swirl the mixture to remove barium ions from the solution.
- step 4 Add 2–3 drops of $\text{K}_2\text{CrO}_4(\text{aq})$ indicator to the flask.
- step 5 Titrate the contents of the flask against $0.0500\text{ mol dm}^{-3}\text{ AgNO}_3(\text{aq})$.
- step 6 Repeat steps 2 to 5 to collect sufficient data for analysis.

(i) Suggest a suitable piece of apparatus for transferring 20.0 cm^3 of solution **A** in step 2.

..... [1]

(ii) Suggest why barium ions are removed in step 3 before performing the titration.

..... [1]

(iii) Suggest why chemically resistant gloves should be worn to carry out step 4.

..... [1]

(c) The student's results are shown in Table 1.1.

Table 1.1

	rough titration	titration 1	titration 2	titration 3
burette reading (final)/ cm^3	20.10	40.55	20.75	20.90
burette reading (initial)/ cm^3	0.00	20.25	0.05	0.30
titre/ cm^3	20.10	20.30	20.70	20.60

The student uses the titres from titrations 2 and 3 shown in Table 1.1 to calculate a mean titre value of 20.65 cm^3 .

(i) Explain why only these two values are used.

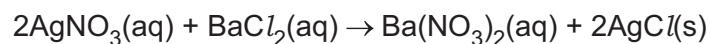
..... [1]



- (ii) Calculate the percentage error in the titre volume for titration 3.
Show your working.

percentage error = [1]

- (d) The equation for the reaction of silver nitrate with barium chloride is shown.



- (i) Calculate the amount, in mol, of $\text{AgNO}_3(\text{aq})$ in the mean titre of 20.65 cm^3 .

amount of $\text{AgNO}_3 = \dots\dots\dots \text{mol}$ [1]

- (ii) Calculate the amount, in mol, of $\text{BaCl}_2(\text{aq})$ in 250 cm^3 of solution **A**.

amount of $\text{BaCl}_2 = \dots\dots\dots \text{mol}$ [1]

- (iii) Calculate the value of x in the formula $\text{BaCl}_2 \cdot x\text{H}_2\text{O}$.

$x = \dots\dots\dots$ [2]



- (e) Another student uses a different experimental method to check the value of x obtained by the method described in (b).

Give a **brief** description of another method, not involving titration, that could be used to determine the value of x in the formula $\text{BaCl}_2 \cdot x\text{H}_2\text{O}(\text{s})$. Write your answer using a series of numbered steps.

Your plan should include details of the following:

- the apparatus and method you would use
- the measurements you would make.

You are provided with standard laboratory apparatus.

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..... [3]

[Total: 16]



- 2 Effusion is the process in which a gas escapes through a small hole.

A student investigates the relationship between rate of effusion and relative molar mass of a gas using the apparatus shown in Fig. 2.1.

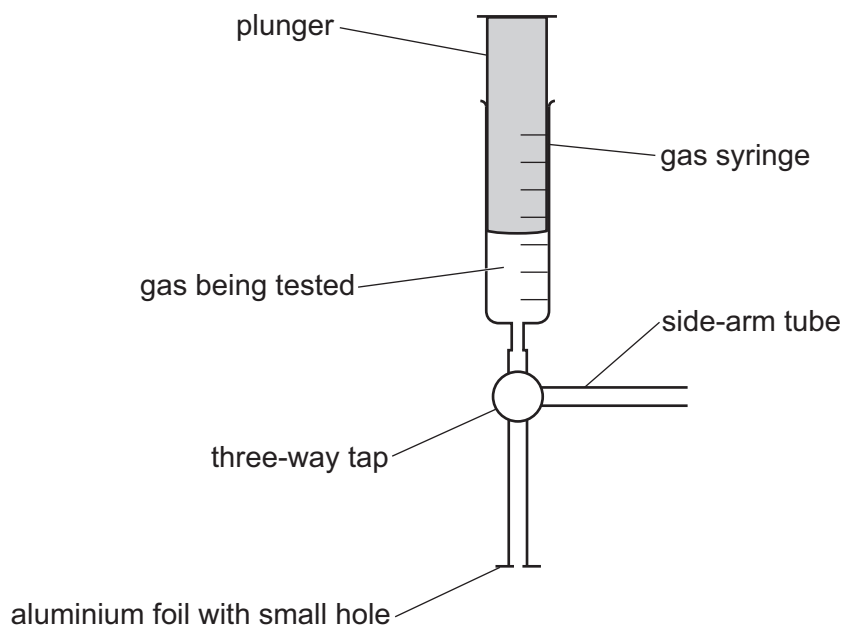


Fig. 2.1

The following method is used:

- step 1 Turn the tap and remove any gas from the syringe through the side-arm tube, by pushing in the plunger.
- step 2 Add 50 cm^3 of the gas being tested to the syringe through the side-arm tube.
- step 3 Remove the gas from the syringe, through the side-arm tube, by pushing in the plunger.
- step 4 Add 70 cm^3 of the gas being tested to the syringe through the side-arm tube.
- step 5 Turn the tap to connect the syringe to the tube with the aluminium foil and small hole.
- step 6 Allow the syringe plunger to fall and start a timer when the volume of gas in the syringe reaches 60 cm^3 .
- step 7 Stop the timer when the volume of gas in the syringe reaches 10 cm^3 . Record the time taken.
- step 8 Repeat steps 1 to 7 with different gases.



- (a) Suggest why the student adds 50 cm^3 of the gas being tested to the syringe in step 2 and then removes this gas in step 3.

.....
 [1]

- (b) The student's results are shown in Table 2.1.

Table 2.1

gas	hydrogen, H_2	helium, He	neon, Ne	argon, Ar	krypton, Kr
relative molar mass, M	2.0	4.0	20.2	39.9	83.8
$\sqrt{\frac{1}{M}}$					
time taken /s	10.8	15.3	34.5	39.7	70.4
rate of effusion / $\text{cm}^3\text{ s}^{-1}$					

$$\text{rate of effusion} = \frac{\text{volume of gas}}{\text{time taken}}$$

- (i) Complete Table 2.1.

Give the values for $\sqrt{\frac{1}{M}}$ to **three** significant figures.

Give the values for rate of effusion to **two** decimal places. [2]

- (ii) Identify the dependent variable in this experiment.

..... [1]

- (iii) Identify a variable, other than temperature, that is controlled when carrying out this experiment.

..... [1]



- (c) Plot a graph on the grid in Fig. 2.2 to show the relationship between rate of effusion and $\sqrt{\frac{1}{M}}$.
Use a cross (×) to plot each data point. Draw a suitable line of best fit.

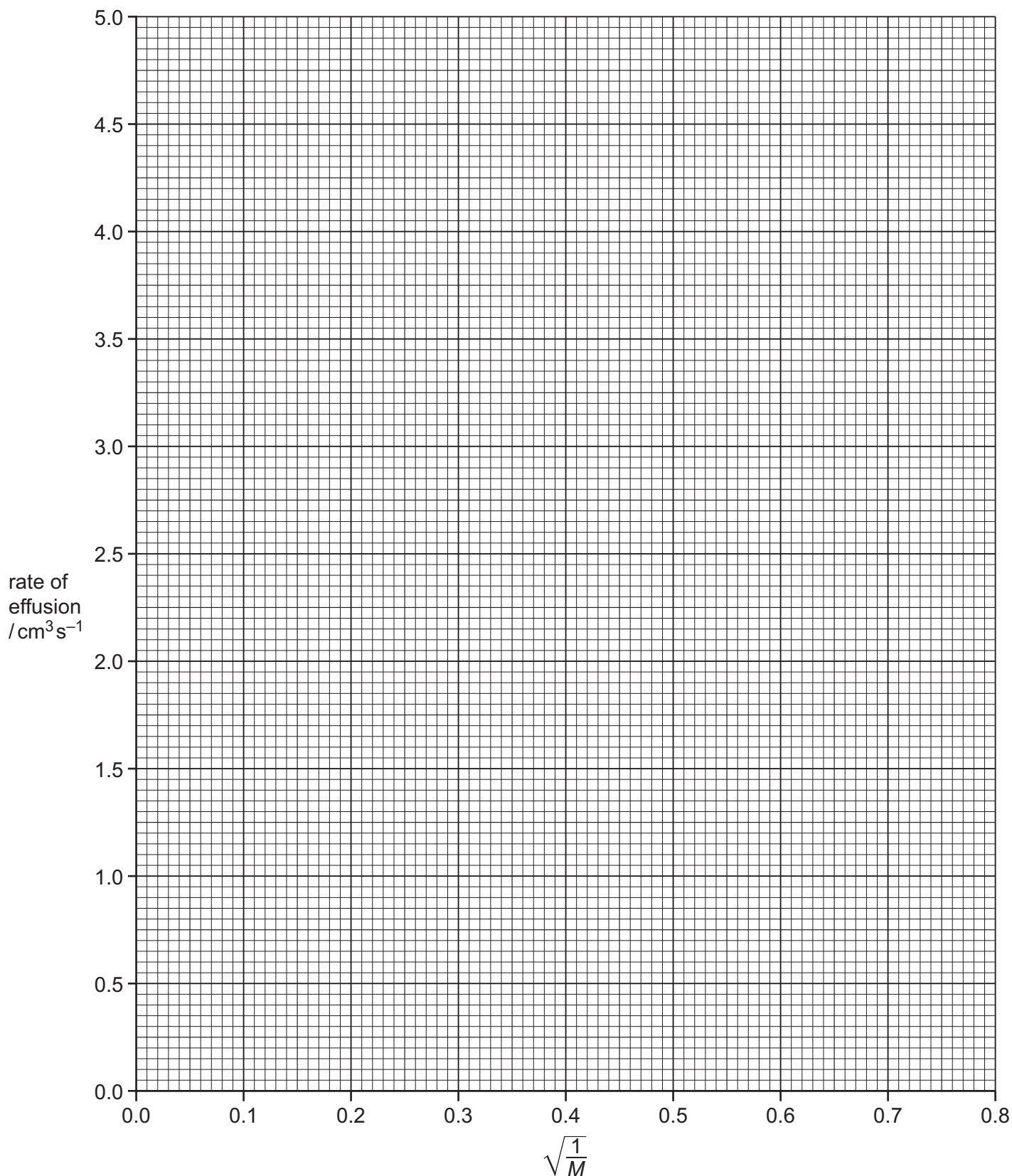


Fig. 2.2

[2]





- (d) Circle **one** point on the graph in Fig. 2.2 which you consider to be most anomalous.

Suggest **one** reason for this anomaly. Assume there is no error in $\sqrt{\frac{1}{M}}$.

.....
 [1]

- (e) Graham's law of effusion can be expressed as:

the rate of effusion of a gas is proportional to $\sqrt{\frac{1}{M}}$.

State whether or not the student's results support Graham's law of effusion.

Explain your answer, using the graph in Fig. 2.2.

.....
 [1]

- (f) Suggest how the position of the plotted points relative to the line of best fit in Fig. 2.2 is related to the reliability of the results.

.....
 [1]

- (g) The student then repeats this method to determine the value of M of a sample of natural gas.

The time recorded in step 7 is 31.6 s.

- (i) Use the graph in Fig. 2.2 and the student's result to calculate the value of M for this sample.

$M =$ [2]

- (ii) Natural gas is a mixture of mainly methane, CH_4 , with small amounts of other gases.

Suggest what your calculated value of the M of natural gas in (g)(i) tells you about the other gases in the mixture.

.....
 [1]



(h) The experiment described in (g) is repeated at a higher temperature.

Suggest how the rate of effusion for this sample of natural gas would change, if at all.

Explain your answer.

effect on the rate of effusion

explanation

[1]

[Total: 14]

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)



The Periodic Table of Elements

Group																	
1	2	1										13	14	15	16	17	18
		1 H hydrogen 1.0															
		Key															
		atomic number atomic symbol name relative atomic mass															
3	4																
Li lithium 6.9	Be beryllium 9.0																
11	12																
Na sodium 23.0	Mg magnesium 24.3																
19	20																
K potassium 39.1	Ca calcium 40.1																
37	38																
Rb rubidium 85.5	Sr strontium 87.6																
55	56																
Cs caesium 132.9	Ba barium 137.3																
87	88																
Fr francium —	Ra radium —																
		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
		Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8
		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
		Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3
		57–71 lanthanoids	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
		Hf hafnium 178.5		Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —
		89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
		Rf rutherfordium —		Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —

lanthanoids

actinoids

57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu
lanthanum	138.9	cerium	140.1	praseodymium	140.9	neodymium	144.2	promethium	—	samarium	150.4	europlum	152.0	gadolinium	157.3	terbium	158.9	dysprosium	162.5	holmium	164.9	erbium	167.3	thulium	168.9	ytterbium	173.1	lutetium	175.0
89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr
actinium	227.0	thorium	232.0	protactinium	231.0	uranium	238.0	neptunium		plutonium		americium		curium		berkelium		californium		einsteinium		fermium		mendelevium		nobelium		lawrencium	

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