14–16 years

Determining the volume of one mole of hydrogen gas

ROYAL SOCIETY OF CHEMISTRY

Education
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Introduction

One mole of any gas occupies the same volume when measured under the same conditions of temperature and pressure.

At room temperature and pressure (RTP) this volume is 24.0 dm^3 or 24,000 cm^3.

In chemistry, room temperature and pressure are 20°C and 1 atmosphere.

1 mole of He

= 24 dm^3

1 mole of O_2

= 24 dm^3

28 g of N_2

= 24 dm^3

Introduction

Magnesium reacts with hydrochloric acid to produce a salt – magnesium chloride – and hydrogen gas.

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

In this experiment, you will measure the volume of gas produced by the reaction of a known mass of magnesium with excess hydrochloric acid.

You will use the results to determine the volume of one mole of hydrogen gas at room temperature and pressure.

Learning objectives

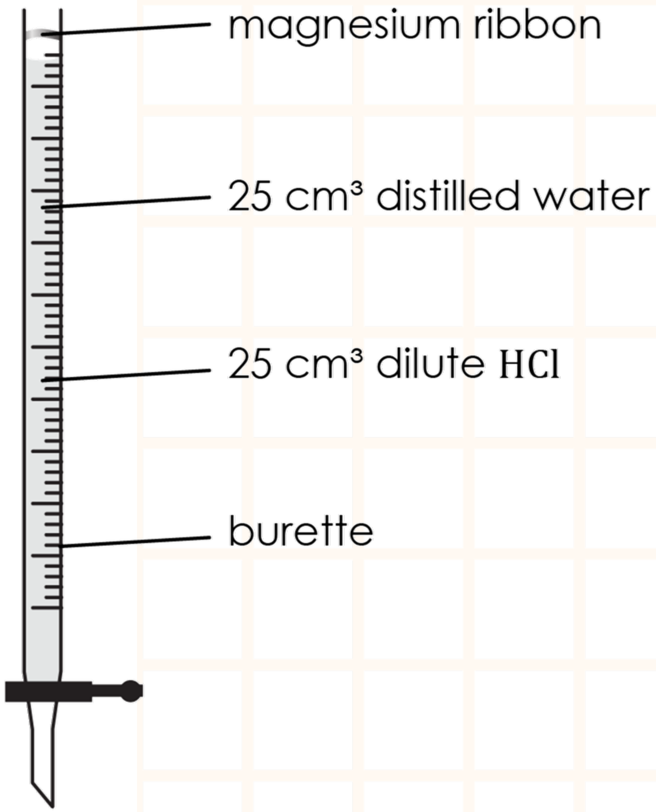
1 Measure the volume of hydrogen gas produced by a metal–acid reaction.

2 Analyse the results to determine the volume of one mole of a gas.

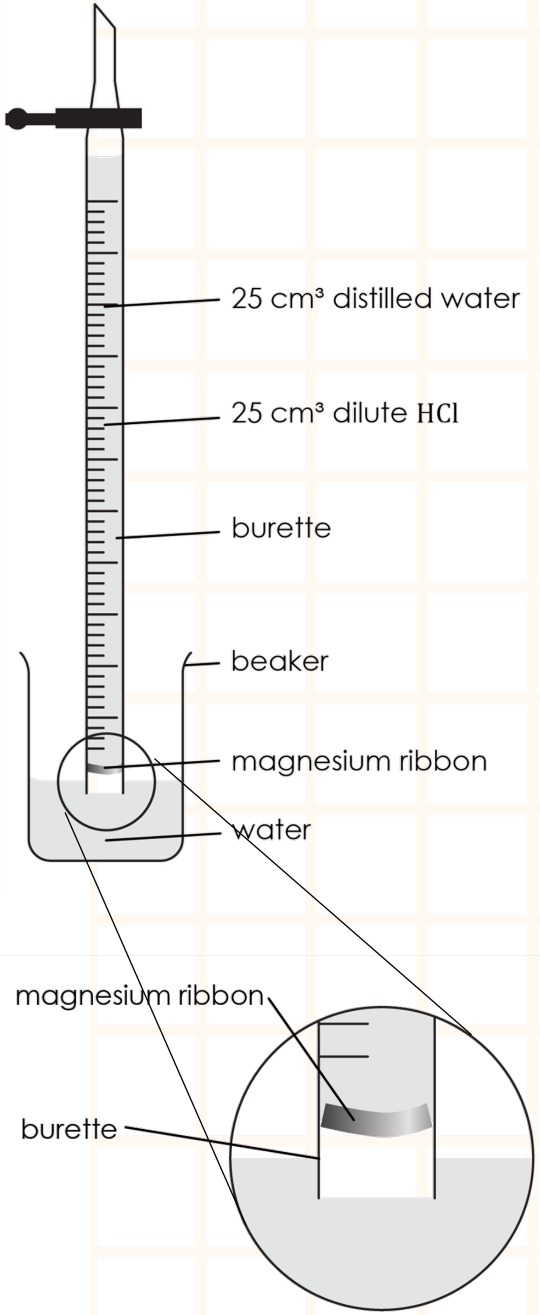
3 Evaluate the accuracy of the result obtained.

Method

1. Clean a piece of magnesium ribbon about 3.5 cm long by gently rubbing it with emery paper and measure its mass accurately. It should have a mass between 0.02 g and 0.04 g. If not, adjust the amount used.
2. Measure 25 cm^3 of 2.0 mol/dm^3 hydrochloric acid into the burette. Slightly tilt the burette and carefully add 25 cm^3 of water on top of the acid by running the water down the inside of the burette. Try not to disturb the acid layer.
3. Push the magnesium into the end of the burette so it will stay in position with its own tension.



4. Add 50 cm^3 of water to a 250 cm^3 beaker.
5. Quickly invert the burette into the water – your teacher will show you how to do this. If this is done quickly and carefully, very little liquid is lost. Clamp the burette vertically.
6. It is important that the liquid level in the burette starts on the graduated scale. If it is not on the scale, momentarily open the tap. This allows the level to drop.
7. Take the burette reading (*Remember:* the burette is upside down).
8. Observe the magnesium reacting as the acid diffuses downwards. Wait until all the magnesium has reacted.
9. Record the new volume in the burette (care: the burette is upside down).



Method

Results and analysis

Mass of magnesium ribbon used (g) ________________

Initial burette reading (cm^3) ________________

Final burette reading (cm^3) ________________

Volume of hydrogen produced (cm^3) ________________

Use your results to calculate the volume of one mole of hydrogen gas under the conditions used.

Results and analysis

A	Mass of magnesium ribbon used / g	
B	Initial burette reading / cm^3	
C	Final burette reading / cm^3	
D	Volume of hydrogen produced / cm^3	B – C =

Complete the results table by calculating the volume of hydrogen produced. This is the difference between the two burette readings.

Results and analysis

Follow the steps to determine the volume of one mole of hydrogen.

Step one

Calculate the amount in mol of Mg reacted.

Relative atomic mass (RAM) of Mg = 24

$$\text{mol} = \frac{\text{mass in g}}{\text{RAM}}$$

Step two

From the balanced equation, 1 mol of Mg produces 1 mol of H_2 gas.

Use this fact to write down the amount in mol of H_2 gas produced based on the amount in mol of Mg you reacted.

Step three

Calculate the volume of 1 mol of H_2 gas by dividing the volume measured by the amount in mol of H_2 produced.

$$\text{volume of 1 mol of } H_2 \text{ in cm}^3 = \frac{\text{volume measured in cm}^3}{\text{amount of } H_2 \text{ produced in mol}}$$

Evaluation ⭐ / ⭐⭐

1. Calculate the percentage difference between your value and the true value for the volume of one mole of gas at RTP. Use the equation:

$$\% \text{ difference} = \frac{\text{difference between the experimental value and the true value}}{\text{true value}} \times 100$$

2. How close was the experimental value to the true value ?

   Suggest two reasons for the difference.

3. How could you improve the experiment to obtain a more accurate value?

Further questions

Answer the following questions about the method used.

4. Why was 25 cm^3 of water added on top of the 2 mol/dm^3 hydrochloric acid in the burette?

5. A student missed the instruction to take care not to disturb the acid layer in step 2 and mixed the acid and water prior to inverting the burette. Describe what impact would this have on the outcome of the experiment.

6. Explain why it was important to use between 0.02 g and 0.04 g of magnesium ribbon.

Further questions

Answer the following questions about the method used.

4. Why was 25 cm^3 of water added on top of the 2 mol/dm^3 hydrochloric acid in the burette?
5. Show by calculation that the hydrochloric acid was in excess.
6. A student missed the instruction to take care not to disturb the acid layer in step 2 and mixed the acid and water prior to inverting the burette. Describe what impact would this have on the outcome of the experiment.
7. Explain why it was important to use between 0.02 g and 0.04 g of magnesium ribbon.

Practice calculations

1. Magnesium reacts with acid to make a salt and hydrogen gas:

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

(a) When 0.5 mol of magnesium is reacted with an excess of hydrochloric acid, how many moles of hydrogen are produced?

(b) Calculate the amount in mol of hydrogen produced from the reaction of 6 g of magnesium with an excess of hydrochloric acid.

2. Lithium reacts with water to produce lithium hydroxide and hydrogen gas:

$$2Li(s) + 2H_2O(aq) \rightarrow 2LiOH(aq) + H_2(g)$$

(a) When 0.5 mol of lithium is reacted with an excess of water, how many moles of hydrogen are produced?

(b) Calculate the amount in mol of hydrogen produced from the reaction of 14 g of lithium with an excess of hydrochloric acid.

3. If 0.05 mol of gas has a volume of 1,200 cm^3 at room temperature and pressure, show by calculation that the volume of 1 mol of gas is 24,000 cm^3.

Practice calculations – answers

1. (a) Number of moles of $H_2 = 0.5\ \text{mol}$

   (b) Number of moles of $\text{Mg} = \frac{6}{24} = 0.25\ \text{mol}$

   Number of moles of $H_2 = 0.25\ \text{mol}$

2. (a) Number of moles of $H_2 = \frac{0.5\ \text{mol}}{2} = 0.25\ \text{mol}$

   (b) Number of moles of $\text{Li} = \frac{14}{7} = 2\ \text{mol}$

   Number of moles of $H_2 = \frac{2}{2} = 1\ \text{mol}$

3. Volume of 1 mol of gas $= \frac{1{,}200\ \text{cm}^3}{0.05\ \text{mol}} = 24{,}000\ \text{cm}^3$

Practice calculations – answers

Practice calculations

In each case, calculate the volume of one mole of gas based on the experimental results.

1. Magnesium reacts with acid to make a salt and hydrogen gas:

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

   0.50 g of magnesium was reacted with excess acid, 0.49 dm^3 of gas was produced.

2. Lithium reacts with water to produce lithium hydroxide and hydrogen gas:

$$2Li(s) + 2H_2O(aq) \rightarrow 2LiOH(aq) + H_2(g)$$

   17.5 g of lithium was reacted with excess water, 31.5 dm^3 of gas was produced.

3. Aluminium reacts with acid to make a salt and hydrogen gas:

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

   3.00 g of aluminium was reacted with excess acid, 3.75 dm^3 of gas was produced.

Practice calculations – answers

1. $$\text{Number of moles of Mg} = \frac{0.50}{24} = 0.0208\ \text{mol}$$

   $$\text{Number of moles of } H_2 \text{ produced} = 0.0208\ \text{mol}$$

   $$\text{Volume of 1 mole of } H_2 = \frac{0.49\ \text{dm}^3}{0.0208\ \text{mol}} = 23.5\ \text{dm}^3\ (\text{to 3 s.f.})$$

2. $$\text{Number of moles of Li} = \frac{17.5}{7} = 2.5\ \text{mol}$$

   $$\text{Number of moles of } H_2 \text{ produced} = \frac{2.5\ \text{mol}}{2} = 1.25\ \text{mol}$$

   $$\text{Volume of 1 mole of } H_2 = \frac{31.5\ \text{dm}^3}{1.25\ \text{mol}} = 25.2\ \text{dm}^3\ (\text{to 3 s.f.})$$

3. $$\text{Number of moles of Al} = \frac{3.0}{27} = 0.111\ \text{mol}$$

   $$\text{Number of moles of } H_2 \text{ produced} = \frac{0.111\ \text{mol}}{2} \times 3 = 0.167\ \text{mol}$$

   $$\text{Volume of 1 mole of } H_2 = \frac{3.75\ \text{dm}^3}{0.167\ \text{mol}} = 22.5\ \text{dm}^3\ (\text{to 3 s.f.})$$