Calculating the gas constant through measuring the volume of hydrogen gas (dm^3)produced in the reaction of hydrochloric acid ($3\ \mathrm{mol}$) and controlled amounts of magnesium (cm)

Leo Chai

White Oaks Secondary School

Calculations

Summary and Organization of results

$$n_l \text{ represent the amount of moles produced by } l \text{ cm of magnesium strip.}$$

$$m_i \text{ represent the molar volume of an ideal gas at STP}$$

$$v_{0.5} \text{ represent the volume of hydrogen gas in } dm^3 \text{ produced by } 0.5cm \text{ of magnesium strip}$$

$$n_{0.5} = \frac{v_{0.5}}{m_i} = \frac{9.80 \times 10^{-3} \pm 5 \times 10^{-5} \cancel{dm^3}}{22.7 \cancel{dm^3} mol^{-1}} = 4.32 \times 10^{-4} \pm 0.51\% \, mol$$

$$n_1 = n_{0.5} \times \frac{1}{0.5 \pm 0.05cm} = 4.32 \pm 0.51\% mol \times \frac{1}{0.5 \pm 10\% cm} = 8.6 \times 10^{-4} \pm 9.03 \times 10^{-5} mol \, cm^{-1}$$

Therefore, there are $8.63mol$ of hydrogen released per 1cm of magnesium.

From this, a function can derived to calculate the volume of hydrogen gas in mol produced by different lengths of magnesium.

$$\text{let } l \text{ represent the length of magnesium used in the reaction}$$

$$\text{let } f(x) \text{ represent the moles of hydrogen gas released per } 1cm \text{ of magnesium}$$

$$f(x) = \frac{v_l}{m_i} \times \frac{1}{l} = \frac{v_l \pm 5 \times 10^{-5} dm^3}{m_i \times l \pm 0.05cm}$$

$$f(1.0cm) = \frac{v_{1.0} \pm 5 \times 10^{-5}}{m_i \times 1.0 \pm 0.05} = \frac{1.65 \times 10^{-2} \pm 0.33\% \cancel{dm^3}}{22.7 \, \cancel{dm^3} mol^{-1} \times 1.0 \pm 5\% cm}$$

$$= 7.3 \times 10^{-4} \pm 3.89 \times 10^{-5} mol \, cm^{-1}$$

$$f(1.3) = \frac{v_{1.3} \pm 5 \times 10^{-5}}{m_i \times 1.3 \pm 0.05} = \frac{2.38 \times 10^{-2} \pm 0.21\% \cancel{dm^3}}{22.7 \cancel{dm^3} mol^{-1} \times 1.3 \pm 3.85\% cm}$$

$$= 8.1 \times 10^{-4} \pm 3.29 \times 10^{-5} \, mol \, cm^{-1}$$

$$f(1.6) = \frac{v_{1.6} \pm 5 \times 10^{-5}}{m_i \times 1.6 \pm 0.05} = \frac{2.56 \times 10^{-2} \pm 0.20\% \cancel{dm^3}}{22.7 \cancel{dm^3} mol^{-1} \times 1.6 \pm 3.12\% cm}$$

$$= 7.0 \times 10^{-4} \pm 2.32 \times 10^{-5} \, mol \, cm^{-1}$$

$$f(2.0) = \frac{v_{2.0} \pm 5 \times 10^{-5}}{m_i \times 2.0 \pm 0.05} = \frac{3.26 \times 10^{-2} \pm 0.15\% \cancel{dm^3}}{22.7 \cancel{dm^3} mol^{-1} \times 2.0 \pm 2.5\% cm}$$

$$= 7.2 \times 10^{-4} \pm 1.908 \times 10^{-5} \, mol \, cm^{-1}$$

Table 1. Chart of the volume of hydrogen gas produced when different length of magnesium reacts in hydrochloric acid.

Length of Magnesium used (cm)	Volume of hydrogen gas produced in total (dm^3)	Amount of hydrogen gas produced per 1cm of magnesium ($mol\ cm^{-1}$)
0.5 ± 0.05	$9.80 \times 10^{-3} \pm 5 \times 10^{-5}$	$8.6 \times 10^{-4} \pm 9.03 \times 10^{-5}$
1.0 ± 0.05	$1.65 \times 10^{-2} \pm 5 \times 10^{-5}$	$7.3 \times 10^{-4} \pm 3.89 \times 10^{-5}$
1.3 ± 0.05	$2.38 \times 10^{-2} \pm 5 \times 10^{-5}$	$8.1 \times 10^{-4} \pm 3.29 \times 10^{-5}$
1.6 ± 0.05	$2.56 \times 10^{-2} \pm 5 \times 10^{-5}$	$7.0 \times 10^{-4} \pm 2.32 \times 10^{-5}$
2.0 ± 0.05	$3.26 \times 10^{-2} \pm 5 \times 10^{-5}$	$7.2 \times 10^{-4} \pm 1.91 \times 10^{-5}$

Pressure of the gas

According to Dalton's law, the total pressure is equal to the sum of the pressure of each element.

$$P_t = P_A = P_H + P_w$$

Where P_t is the total pressure, P_A is the atmospheric pressure, P_H is the pressure on hydrogen gas and P_w is the pressure of water vapor.

$$\therefore P_H = P_A - P_w = 100.294 \pm 0.001 kPa - 3.040 \pm 0.002 kPa = 97.254 \pm 0.003 kPa$$

Calculating the universal gas constant

According to the Ideal Gas Law: $PV = nRT$

Where P represents the pressure, V resents the volume, n represent the amount of mols, T represents the temperature and R represents the universal gas constant.

$$\therefore R = \frac{nT}{PV}$$

Since V represents the volume of hydrogen gas produced per 1cm of Magnesium, it can be calculated from the function $V(l) = \frac{V_l}{l}$

$$V(0.5) = \frac{9.80 \times 10^{-3} \pm 5 \times 10^{-5} dm^3}{0.5 \pm 0.05 cm} = \frac{9.80 \times 10^{-3} \pm 0.51\% dm^3}{0.5 \pm 10\% cm} = 1.98 \times 10^{-2} \pm 10.51\% dm^3\ cm^{-1}$$

$$V(1.0) = \frac{1.65 \times 10^{-2} \pm 5 \times 10^{-5} dm^3}{1.0 \pm 0.05 cm} = \frac{1.65 \times 10^{-2} \pm 0.33\% dm^3}{1.0 \pm 5\% cm} = 1.65 \times 10^{-2} \pm 5.33\% dm^3\ cm^{-1}$$

$$V(1.3) = \frac{2.38 \times 10^{-2} \pm 5 \times 10^{-5} dm^3}{1.3 \pm 0.05 cm} = \frac{2.38 \times 10^{-2} \pm 0.21\% dm^3}{1.3 \pm 3.85\% cm} = 1.83 \times 10^{-2} \pm 4.56\% dm^3\ cm^{-1}$$

$$V(1.6) = \frac{2.56 \times 10^{-2} \pm 5 \times 10^{-5} dm^3}{1.6 \pm 0.05 cm} = \frac{2.56 \times 10^{-2} \pm 0.20\% dm^3}{1.6 \pm 3.12\% cm} = 1.60 \times 10^{-2} \pm 3.32\% dm^3\ cm^{-1}$$

$$V(2.0) = \frac{3.26 \times 10^{-2} \pm 5 \times 10^{-5} dm^3}{2.0 \pm 0.05 cm} = \frac{3.26 \times 10^{-2} \pm 0.15\% dm^3}{2.0 \pm 2.5\% cm} = 1.63 \times 10^{-2} \pm 2.65\% dm^3\ cm^{-1}$$

The function $R(l)$ can thus be created to calculate universal gas constant from different lengths of magnesium used.

$$R(l) = \frac{PV_l}{n_l T}$$

$$R(0.5) = \frac{PV_l}{n_l T} = \frac{97.254 \pm 0.003\ kPa\ \ dm^3 \times 1.98 \times 10^{-2} \pm 10.51\%\ cm^{-1}}{8.6 \times 10^{-4} \pm 9.03 \times 10^{-5}\ mol\ cm^{-1}\ \times 244 \pm 2\ K}$$

$$= \frac{97.254 \pm \times 3.08 \times 10^{-3}\%\ kPa\ \ dm^3 \times 1.98 \times 10^{-2} \pm 10.51\%\ \cancel{cm^{-1}}}{8.6 \times 10^{-4} \pm 10.51\%\ mol\ \cancel{cm^{-1}}\ \times 244 \pm 0.82\%\ K}$$

$$= 9.9455 \pm 21.84\%\ Jmol^{-1} = 9.9455 \pm 2.17\ Jmol^{-1}$$

$$R(1.0) = \frac{PV_l}{n_l T} = \frac{97.254 \pm 0.003\ kPa\ \ dm^3 \times 1.65 \times 10^{-2} \pm 5.33\% cm^{-1}}{7.3 \times 10^{-4} \pm 3.89 \times 10^{-5}\ mol\ \ cm^{-1}\ \times 244 \pm 2\ K}$$

$$= \frac{97.254 \pm 3.08 \times 10^{-3}\%\ kPa\ \ dm^3 \times 1.65 \times 10^{-2} \pm 5.33\%\ \cancel{cm^{-1}}}{7.3 \times 10^{-4} \pm 5.33\% mol\ \cancel{cm^{-1}}\ \times 244 \pm 0.82\%\ K}$$

$$= 9.8134 \pm 11.48\%\ Jmol^{-1} = 9.8134 \pm 1.13\ Jmol^{-1}$$

$$R(1.3) = \frac{PV_l}{n_l T} = \frac{97.254 \pm 0.003\ kPa\ \ dm^3 \times 1.83 \times 10^{-2} \pm 4.56\%\ cm^{-1}}{8.1 \times 10^{-4} \pm 3.29 \times 10^{-5}\ mol\ cm^{-1}\ \times 244 \pm 2\ K}$$

$$= \frac{97.254 \pm 3.08 \times 10^{-3}\%\ kPa\ \ dm^3 \times 1.83 \times 10^{-2} \pm 4.56\%\ \cancel{cm^{-1}}}{8.1 \times 10^{-4} \pm 4.56\%\ mol\ \cancel{cm^{-1}}\ \times 244 \pm 0.82\%\ K}$$

$$= 9.8090 \pm 9.94\%\ Jmol^{-1} = 9.8090 \pm 0.975\ Jmol^{-1}$$

$$R(1.6) = \frac{PV_l}{n_l T} = \frac{97.254 \pm 0.003\ kPa\ \ dm^3 \times 1.60 \times 10^{-2} \pm 3.32\%\ cm^{-1}}{7.0 \times 10^{-4} \pm 2.32 \times 10^{-5}\ mol\ cm^{-1}\ \times 244 \pm 2\ K}$$

$$= \frac{97.254 \pm 3.08 \times 10^{-3}\%\ kPa\ \ dm^3 \times 1.60 \times 10^{-2} \pm 3.32\%\ \cancel{cm^{-1}}}{7.0 \times 10^{-4} \pm 3.32\%\ mol\ \cancel{cm^{-1}} \times 244 \pm 0.82\%\ K}$$

$$= 9.9239 \pm 7.46\%\ Jmol^{-1} = \ 9.9239 \pm 0.740\ Jmol^{-1}$$

$$R(2.0) = \frac{PV_l}{n_l T} = \frac{97.254 \pm 0.003\ kPa\ \ dm^3 \times 1.63 \times 10^{-2} \pm 2.65\%\ cm^{-1}}{7.2 \times 10^{-4} \pm 1.91 \times 10^{-5}\ mol\ cm^{-1}\ \times 244 \pm 2\ K}$$

$$= \frac{97.254 \pm 3.08 \times 10^{-3}\%\ kPa\ \ dm^3 \times 1.63 \times 10^{-2} \pm 2.65\%\ \cancel{cm^{-1}}}{7.2 \times 10^{-4} \pm 2.65\%\ mol\ \cancel{cm^{-1}} \times 244 \pm 0.82\%\ K}$$

$$= 9.8291 \pm 6.12\%\ Jmol^{-1} = 9.8291 \pm 0.602\ Jmol^{-1}$$

Table 2. Chart of the universal gas constant from measured amount of hydrogen gas produced from reaction of different length of magnesium with hydrochloric acid

Length of Magnesium used (cm)	Universal Gas Constant calculated ($Jmol^{-1}$)	Uncertainty ($Jmol^{-1}$)
0.5 ± 0.05	9.9455	± 2.17
1.0 ± 0.05	9.8134	± 1.13
1.3 ± 0.05	9.8090	± 0.975
1.6 ± 0.05	9.9239	± 0.740
2.0 ± 0.05	9.8291	± 0.602

Determining Errors

$$\text{Percentage Error} = \left|\frac{result\ average - Literature\ value}{Literature\ value}\right| \times 100\%$$

$$= \left|\frac{\frac{R(0.5) + R(1.0) + R(1.3) + R(1.6) + R(2.0)}{5} - 8.31\ Jmol^{-1}}{8.31\ Jmol^{-1}}\right| \times 100\%$$

$$= \left|\frac{9.86018 - 8.31\ Jmol^{-1}}{8.31\ Jmol^{-1}}\right| \times 100\% = \left|\frac{9.86018 - 8.31\ Jmol^{-1}}{8.31\ Jmol^{-1}}\right| \times 100\%$$

$$= 18.65\%$$

Limitations and Improvements

Table 3. Limitations and possible improvements of the experiment

Uncontrolled variable	Impact on result	type	Improvement
Width and height of the Magnesium strip	The ratio between the lengths may not be an accurate representation of the ratio between the volume of the magnesium in the reaction. Thus, the ratios when calculating the hydrogen gas released per a unit volume may not be accurate.	Systematic	Instead of measuring length of Magnesium strip, the mass should be measured instead. This way, it makes sure that the amount of magnesium have a valid ratio to determine results of the reaction.
Gas leaking into the 10 cm^3 graduated cylinder when transferring the cylinder around.	Gas often leaks into the cylinder when transferring the graduated cylinder between places, since at some instances the only barrier at some instances is one’s hand. This would directly affect the amount of hydrogen measured, and thus the results	Systematic	Use a cap that is able to seal the cylinder completely so that there would be no worries of gasses leaking into the graduated cylinder.
Room temperature and pressure is not at STP	The molar volume if Ideal gas is a required constant for this experiment as it is involved directly in the calculations. However, molar volume of Ideal gas is only known for it at STP condition, which is not the condition which the experiment is performed under. This will cause	Systematic	Preform the experiment in an environment which is at STP or have the hydrogen’s molar mas as a known constant for the experimenting environment.

Uncontrolled variable	Impact on result	type	Improvement
	uncertainties in the calculation, as the actual molar volume of hydrogen will be different.		
The amount of hydrogen while measuring	The amount of hydrogen in the graduated cylinder is measured by reading the values on the side of the cylinder when the transparent liquid in and outside of the cylinder line up. With the similar color, observers may measure different value of hydrogen gas from the actual amount.	Random	Dye a liquid with food coloring so that the two liquids are more distinguishable for observers, which may allow more accurate measuring of the amount of hydrogen. More trials should also be preformed to minimize the effect of this random error.
The time taken for the reaction to finish	The end of the reaction was judged by eye, and some samples may be measured without the reaction fully complete. This would directly change the amount of hydrogen in the cylinder and thus impact the results	Systematic	Before the experiment, determine an time which a certain amount of magnesium takes to react with hydrochloric acid, and use that time as reference to wait during the experiment.