For his extended VCE Chemistry experimental investigation project, Chris decided to investigate whether there is a relationship between the rate of the reaction between magnesium, Mg, and hydrochloric acid, HCl, and the concentration of the acid. The following is an extract from the scientific poster that Chris produced.

Question under investigation:
Is there a relationship between the rate of the reaction between magnesium, Mg, and different concentrations of hydrochloric acid, HCl?

Equation for the reaction:

$$Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$$

Experimental design:
Four different concentrations of HCl were tested. The rate of each reaction was investigated by measuring the volume of hydrogen, H_2, gas produced at 60-second intervals.

Hypothesis:
The greater the concentration of the acid, the faster the reaction will be. I expect this because, for a reaction to occur, H^+ ions must collide with Mg atoms. The greater the concentration of the acid, the more frequently the H^+ ions will collide with the surface of the Mg and so the greater the amount of H_2 gas that will be produced.

a. In his hypothesis, does Chris demonstrate an understanding of the chemistry that is relevant to this experimental investigation? Explain your reasoning.
He correctly states that the reaction rate depends on the concentration of hydrochloric acid. His reasoning aligns with collision theory, as a higher concentration of H^+ ions leads to more frequent collisions between H^+ ions and Mg atoms. *1----mark*
Additionally, a greater collision frequency increases the ***number*** *of collisions with energy equal to or greater than the activation energy, leading to more* ***successful (fruitful) collisions****. This explains why the reaction proceeds at a faster rate when the acid concentration is higher.* *1----mark*

In his poster, Chris outlined how the experimental investigation was conducted. An extract from his methodology is shown in the table below, diagram 1.

Methodology: First, the variables were identified. The decisions I made are shown in Table 1.

Table 1. The variables identified

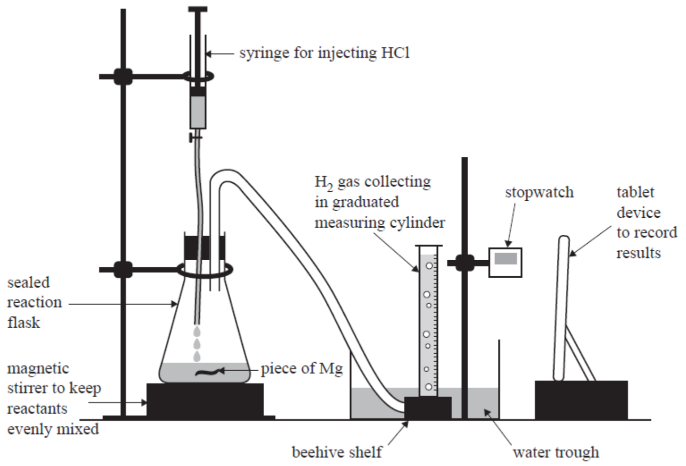
Variable	Classification	Details
mass of Mg	controlled variable	The first piece of Mg ribbon was weighed and measured, then the same length of Mg was used for each concentration of HCl tested.
concentration of HCl	dependent variable	0.5 M, 1.0 M, 1.5 M and 2.0 M solutions of HCl were tested.
volume of HCl	controlled variable	50.0 mL was used for each test, measured using a graduated measuring cylinder.

b. Is Chris's identification of the concentration of HCl as the dependent variable correct? Give a reason for your answer.

No, Chris's identification of the concentration of HCl as the dependent variable is incorrect. 1----mark

*The dependent variable is the **rate of reaction**, which is measured by the volume of hydrogen gas (H_2) produced over time. The **concentration of HCl** is the **independent variable** because it is deliberately changed to observe its effect on the reaction rate 1----mark*

The experimental set-up:



Notes:

- Timing began the instant I started injecting the acid from the syringe above the flask onto the piece of Mg.
- The stopwatch was mounted next to the graduated measuring cylinder, and the volume and time were recorded using a video app on a tablet device and replayed in slow motion to allow the results to be obtained.
- The injection of 20.0 mL HCl into the sealed reaction flask immediately pushed 20.0 mL of air out of the flask and into the measuring cylinder. I recorded only the net volume of H_2 gas produced.

Diagram 1

c. Chris's poster included a diagram of the experimental set-up supported by short notes, as shown above in diagram 1. Identify **one** feature of Chris's experimental set-up and notes above that was designed to improve the accuracy of the results. Explain how this feature could improve accuracy. ` 3 marks

One feature designed to improve accuracy is the use of a video app to record the experiment and replay it in slow motion. 1----mark

This improves accuracy because it allows for precise timing and volume measurements, reducing human reaction time errors when starting or stopping the stopwatch and reading the measuring cylinder. 1----mark

By replaying the video in slow motion, Chris could ensure that volume readings were taken at the exact moment required, minimising errors in data collection and improving the reliability of the recorded results. 1----mark

Chris also recorded his observations on his poster.

Observations: *For the 2.0 M HCl, initially there was very rapid bubbling in the flask. The bubbling slowed over time. All Mg appeared to have dissolved. The flask became very hot. For the 1.5 M and 1.0 M HCl solutions, the bubbling was not as rapid as for the 2.0 M HCl and for the 0.5 M HCl it was much slower. The solutions were still bubbling when timing stopped. The flasks became hot, although not as hot as the flask containing 2.0 M HCl.*

d. Comment on Chris's observations, including the differences in the rate of bubbling and how well the experiment had been controlled. 3 marks

*Chris's observations support the hypothesis that a higher concentration of HCl leads to a faster reaction rate. The **more rapid bubbling in higher concentrations of HCl** indicates a faster production of hydrogen gas, consistent with collision theory, as a greater number of H^+ ions increases the frequency of collisions with Mg.* *1---- mark*

*The **slowing of bubbling over time** suggests that the reaction rate decreases as the reactants are consumed, which aligns with expected reaction kinetics. The fact that some reactions were still bubbling when timing stopped indicates that lower concentrations of HCl reacted more slowly and had not yet reached completion.* *1----mark*

*Chris needed to control for temperature. The **increase in temperature of the flask** suggests that heat from the exothermic reaction may have affected reaction rates, potentially introducing variability in results.* *1-----mark*

Chris replayed his video in slow motion, recorded his experimental results in his logbook and produced a graph for his poster. The graph is shown below in diagram 2.

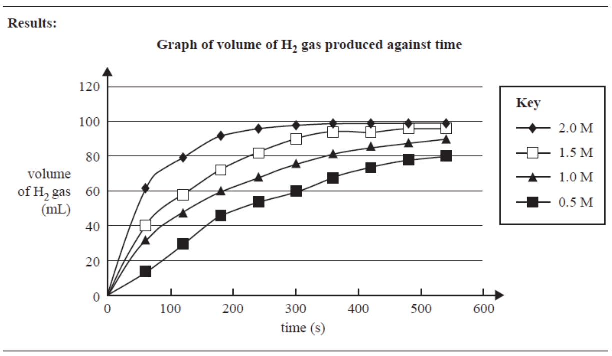


Diagram 2

e. With reference to the data in diagram 2 and Chris' hypothesis give two conclusions that Chris may have stated.

Judging by the results in the diagram 2, Chris may have concluded that there is a direct relationship between the concentration of hydrochloric acid and the rate of reaction with magnesium, by reference to the gradient of each curve in the first 100 seconds. *1-----mark*

His observations showed that higher concentrations of HCl produced hydrogen gas more rapidly, indicated by faster bubbling and a quicker disappearance of Mg.

This supports his hypothesis that a greater concentration of acid leads to a faster reaction, as higher H^+ ion concentrations increase the frequency of collisions with Mg atoms.

Additionally, the experiment demonstrated that the reaction rate slows over time as reactants are consumed *1-----mark*

f. Suggest **one** other question Chris could ask to extend this experimental investigation and briefly outline an experimental design that would enable Chris to answer this question. You may present your answer as a list of main steps. Include a step that minimises the impact of random errors and steps that test for repeatability. 4 marks

Any valid variable is accepted.
How does temperature affect the rate of reaction between magnesium and hydrochloric acid?
1-----mark

Experimental Design?

1. Prepare four 4 identical 100 mL conical flasks with 50 mL of 1 M HCl .
2. Carefully measure four 3.0 cm strips of clean magnesium ribbon.
3. Place each of the four flasks in one of the prepared water baths set at 10°C, 25°C, 40°C, 60°C.
4. Remove the first flask from the 10 °C water bath and place on an electronic balance. Zero the balance.
5. Place a 3.0 cm strip of Mg into the acid and immediately start timing. Record the results every 30 seconds, constantly monitoring and adjusting the temperature using a small ice bath, so that the temperature remains constant during the trial.
6. Repeat steps 4 -5 four more times.
7. Average the concordant results, removing all outliers.
8. Using the next highest temperature water bath, repeat steps 4-7.

1-----mark - Method clearly enables the investigation of the impact of temperature on rate of reaction
1----- mark - for using repeat statements
1-----mark - for logical, sequential, numbered steps.

g. In your procedure identify which steps:

i. test for repeatability ____*step 6*________________1 mark

Explain - *By repeating the same test, at a given temperature, multiple times, Chris can see if the rate of reaction is similar each time. If the results are consistent, the method is considered* ***repeatable****.* *1-----mark*

____

ii. leads to results with high validity *any one of the following, 1,2,3,5or7* ______1 mark

Explain –

- *Step 1 ensures identical flasks and volumes of acid for every trial (controlled variable).*
- *Step 2 uses magnesium strips of the same length (controlled variable).*
- *Step 3 ensures the starting temperature is controlled (controlled variable).*
- ***Step 5*** *includes constant temperature* ***monitoring and adjustment****, which further reduces variation between trials. (controlled variable).*
- *Step 7 improves accuracy by* ***removing outliers*** *and* ***averaging concordant results****, helping to smooth out small, unpredictable random errors.*

1----- mark

iii. use equipment prone to producing systematic errors ____*4*_____1 mark
What impact will this have on the trend of mass loss across all temperatures?
- *A systematic error from the balance, such as incorrect zeroing, will* ***shift all mass loss values*** *either slightly higher or lower, but the* ***overall trend across temperatures will remain the same****.* *1------ mark*

h. What must the method have in order to give results with high validity? 1 mark
The method must control all variables except temperature so that any change in reaction rate is only due to the temperature difference. Only one independent variable.

2. A laboratory wished to study the impact of an equilibrium system, shown below, as stresses are applied at constant temperature.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

The procedure is shown below.

1. Prepare a series of four equilibrium mixtures:
   - In a set of test tubes, mix different volumes of Fe^{3+} and SCN^{-} solutions with water to maintain a constant total volume of 10.00 mL.
   - Keep the initial concentration of one ion constant (Fe^{3+}) and vary the concentration of SCN^{-} to observe how equilibrium shifts.

2. Allow the mixtures to reach equilibrium:
   - Let the solutions stand at constant room temperature, for at least 10 minutes until equilibrium is established.

3. Measure absorbance:
   - Use a spectrophotometer to measure the absorbance of each equilibrium mixture at 447 nm, where $FeSCN^{2+}$ forms a deep red ion complex that strongly absorbs light at 447 nm.

4. Prepare a calibration curve:
   - Make a standard solution containing a known concentration of $FeSCN^{2+}$ by mixing excess Fe^{3+} and a known amount of SCN^{-} .
   - Measure its absorbance and prepare a calibration curve, fig 4, (absorbance vs. [$FeSCN^{2+}$]).

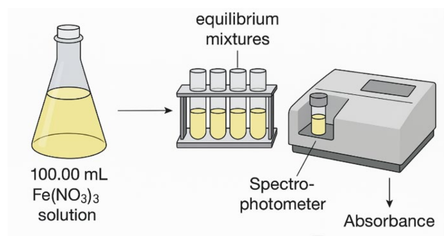


Diagram 3

5. Calculate [Fe^{3+}] at equilibrium:
Use initial concentrations and the amount of Fe^{3+} consumed (based on [$FeSCN^{2+}$]) to calculate the free Fe^{3+} concentration at equilibrium.

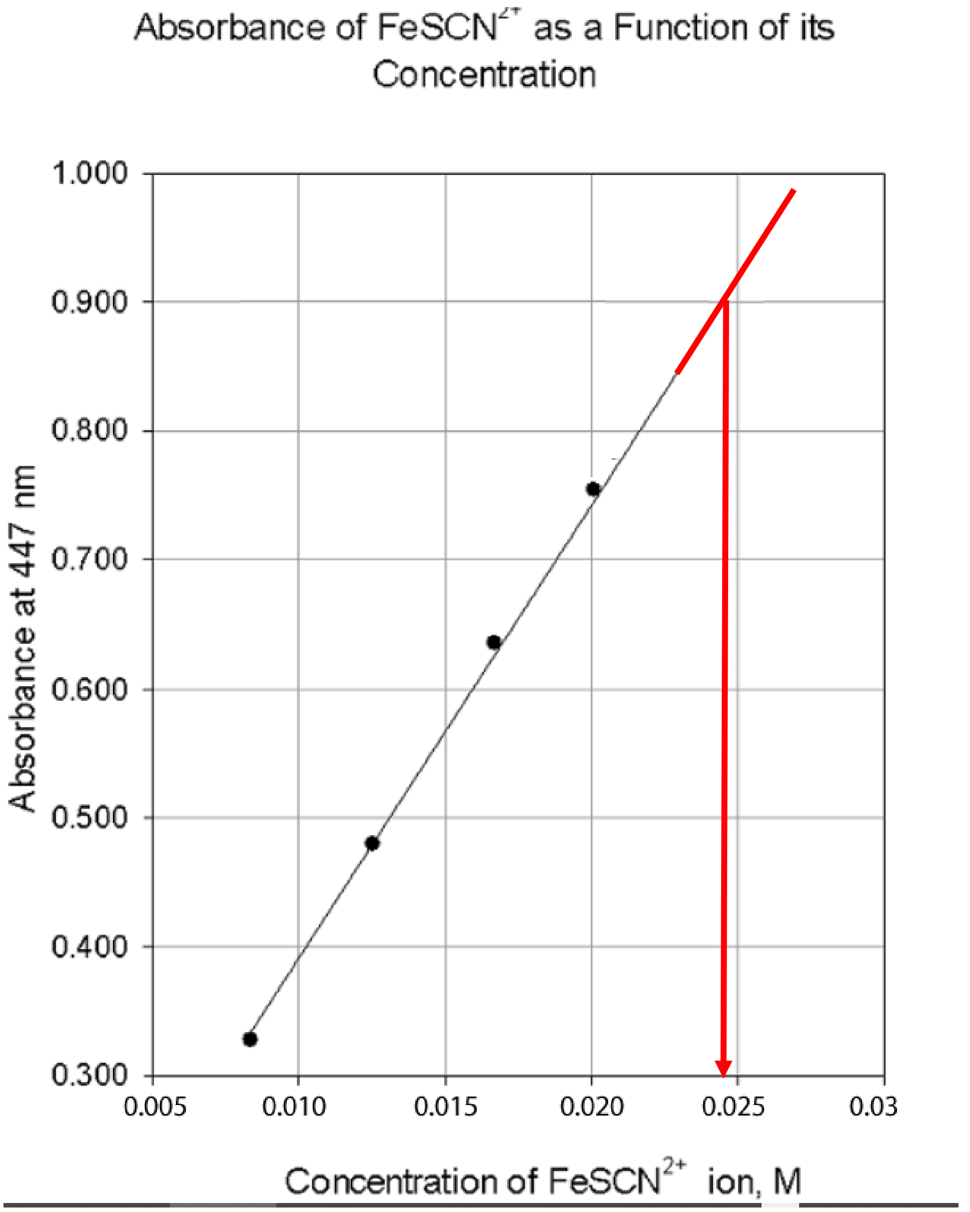


Diagram 4

a. What are the:

DV *Initial concentration of SCN^-* 1 mark

and

IV *Equilibrium concentration of Fe^{3+}* 1 mark

b. Name three controlled variables: 3 marks

i. ______________*Total volume of solution*____________________________

ii. ________________*Temperature*_______________________________________

iii. ________________*Same spectrophotometer* _________________________________

c. One sample had an initial [Fe^{3+}] of 0.035 M. It was allowed to reach equilibrium at which point the absorbance due to [$FeSCN^{2+}$] was 0.9 absorbance units (au).

i. Using the calibration curve, shown in fig. 4, state the concentration of [Fe^{3+}]. Clearly indicate on the graph how you arrived at the value. 2 marks

Accurate extrapolation of graph 1----- mark
Correct reading off the graph as 0.024 or 0.025 and correct value of [Fe^{3+}] at equilibrium of 0.010M or 0.011M. 1----mark

ii. Discuss the degree of accuracy of this result and justify your answer.

Relatively Inaccurate 1----mark
Due to the fact that the reading is outside the sampling range 1-----mark

j. In step 4 of the procedure above, it states, " Make a standard solution containing a known concentration of $FeSCN^{2+}$ by mixing excess Fe^{3+} and a known amount of SCN^{-}. A student questioned whether it was possible to make a solution with a known concentration of $FeSCN^{2+}$ as the equilibrium concentration of SCN^{-} is unknown. Using Le Chatelier's principle discuss the validity of this approach. 3 marks

Excess Fe^{3+} will drive the equilibrium to the right.1-----mark
Very little SCN^{-} should remain when equilibrium is reached. 1-----mark
Since SCN^{-} is almost totally used up the concentration of $FeSCN^{2+}$ at equilibrium can be calculated. 1-----mark

k. Another student opted to use a different method of finding the [Fe^{3+}] at equilibrium. They added excess Na_3PO_4 (aq) to the equilibrium mixture to precipitate out the Fe^{3+} (aq) from solution as $FePO_4$ (s). They then filtered, dried and weighed the precipitate. Compare the validity of the two methods.

One mark for identifying that the spectrophotometer method will lead to results that have a high validity. 1-----mark
The spectrophotometer analysis does not interfere with the equilibrium system, Eg no ions are removed from the system. 1-----mark
The precipitation method removes ions from the system thus applying a stress to the system which it responds by moving to the left. 1----mark
By moving to the left more Fe^{3+} ions are produced until all the $FeSCN^{-}$ has completely dissociated and all the Fe^{3+}in the system has been precipitated out. This give a wrong value for the [Fe^{3+}] at equilibrium 1-----mark