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Investigation on reaction rate of $Mg(s) + 2HCl(aq) \rightarrow MgCl2(aq) + H2(g)$ in changing temperature.

Research Question: What is the effect of changing temperature (0, 10 20, 30, 40) in degree celsius of hydrochloric acid on the rate of reaction(s^-1) in the chemical reaction of $Mg(s) + 2HCl(aq) \rightarrow MgCl2(aq) + H2(g)$ with HCl concentration of 1 mol in 30 seconds.

Chemical reactions are a universal phenomenon in daily life. From rusting iron to baking bread, many activities require or contain chemical reactions. People have always wondered about the factors that affect substances' reaction rates. Some chemical reactions are rapid, while some are gradual and slow. In this experiment, the rate of reaction of hydrochloric acid and magnesium will be studied and investigated. Temperature will be the independent variable and reaction rate will be the dependent variable.

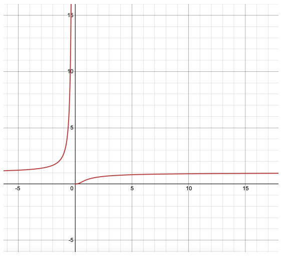
The rate of reaction depends on temperature. The correlation is that as temperature increases, the rate of reaction increases. The phenomenon can be explained by laws of thermodynamics, molecular thermal motion and the essence of the chemical reaction. In the experiment, the hydrochloric acid solution and magnesium are heated. There is an outside heat input to the isolated thermodynamic system. According to the first fundamental law of thermodynamics, when the system goes from the initial state to the final state through any process, the increase in internal energy should equal the difference between the heat transferred to the system and the work done by the system. To describe the law concretely, a mathematical formula is given as (Drake, 2020),

$$\Delta U = Q - \int_{\mathrm{I}}^{\mathrm{II}} p dV$$

The left-hand side is the increase of heat energy of the isolated system, and the right-hand side is the difference between the input of heat and work. In this experiment, the work the system does to the outside can be neglected. Then, a final description is derived---U=Q. Thus, the temperature of the hydrochloric acid solution and magnesium increases, and the intensity of the thermal motion of particles increases. Temperature is a macroscopic measurement of the average molecular kinetic energy. It means that an increase in temperature will increase the kinetic energy of molecules in the system. Since total Ek can be determined by ½mv^2*N, (m =mass of the particles, v =velocity, and N= total number of particles in the system, then, as Ek increases, the velocity increases. So, the particles in hydrochloric acid and magnesium are moving faster. Since the number of particles and space for the reaction stays the same, particle collisions will become more frequent. In the chemical reaction collision theory, the collision of molecules is the precondition of a chemical reaction. The particles' kinetic energy breaks the bonding energy between chemical bonds during the collision. Then, a new chemical bond is formed by the fractions of the broken chemical bond. As particles move faster, the chance of colliding increases. Fast-moving particles increase chemical reaction collision theory's essential factors-- Orientation of collision and collision energy. As a result, more chemical bonds will be broken, and that is how an increase in temperature increases the reaction rate.

To investigate the specific relationship between temperature and the rate of reaction, the Arrhenius equation must be introduced. It is proposed by Savante Arrehenius that points out the dependence of rate of chemical reaction on temperature. The equation goes as follows:

$k = Ae^{\frac{-E_a}{RT}}$ (Lower , 2021) where k is the rate constant, T is the temperature and the rest are other numerical constants that will not be introduced in this paper. For investigation purposes, a graph of $e^{-1/x}$ is graphed to model the mathematical relationship described in the Arrhenius equation.



As x goes to infinity, the y value approaches infinity. The temperature expressed in kelvin is always positive because, according to the third law of thermodynamics, absolute zero is unachievable. Thus, it can be inferred that temperature and reaction rate satisfies the relationship shown in the graph. Due to possible variations of the constants in the equation, the graph might be vertically stretched. All in all, the dependent variable has a complex exponential relationship with the independent variable. A previous lab that investigated the relationship between temperature and rate of reaction shown by gas pressure suggests a linear correlation with R^2 value of 0.7952. The reliability and accuracy of the data and line of best fit is moderately strong, but not exceptional. Thus, it’s also possible that the reaction rate and temperature follow an approximate linear relationship.

In this chemical reaction, magnesium is a solid, shiny, grey, reactive metal reactant with an atomic number of 12. It will be represented as Mg in the lab report. Hydrochloric acid is another reactant in liquid form. The process of reaction can be expressed as the equation: $Mg(s) + 2HCl(aq) \rightarrow MgCl2(aq) + H2(g)$

It is a single displacement reaction, meaning that another element replaces one element in a compound(Anne Marie, 2019). It can be illustrated as $A+BC \rightarrow AC+B$. In the reaction, Mg is the element before reacting, and 2HCl is the compound. Afterwards, MgCl2 is the compound, and H2 becomes an element. In an Mg atom, there are two valence electrons in orbit. After reacting, these two valence electrons will escape, turning Mg into a cation with a charge of 2+. At the same time, the hydrogen gas will combine with itself. Since it has only one valence electron, the two atoms will share the valence electrons to become stable. Cl can only turn into an anion with charge 1-. After the reaction, the Mg cation combines with two Cl anions to neutralise the charge, giving MgCl2, while H2 gas is isolated.

The rate will be measured to investigate its numerical relationship to temperature in the experiment. The process is as follows. The reaction flask will submerge into a water bath with 0, 10, 20, 30 and 40 degrees Celsius to manipulate the independent variable: temperature, during the reaction. The HCl acid will finally arrive at the temperature of the water bath. These five independent variable values are chosen because making the water bath an exact value under zero degrees is hard in a high school lab. It is difficult to monitor the temperature using a thermometer since ice is solid, and the testing part of the thermometer will not be able to be surrounded by the object tested. Temperature beyond 40 degrees is not chosen because it can be dangerous to heat HCl acid over 40 degrees since poisonous gas will be released at 50 degrees celsius (Bull, 2007). There will be four trials for each temperature. Then, one magnesium strip of 2 cm will be put into the flask with hydrochloric acid of 1 mol for 30 seconds. The emitted H2 gas will be led to a reversed eudiometer with water by a rubber tube. Since the hydrogen gas is not soluble in water, the water in the reversed eudiometer will be displaced and pushed down. For each temperature value, the volume of H2 gas emission (the volume of water displaced) will be measured by subtracting the initial number from the final number on the eudiometer. If the reaction time is over 30 seconds, the water displacement will be too big, causing measurement difficulty. If it is shorter than 30 seconds, water displacement will not be noticeable. Comparing the magnitude of water displacement per unit time, calculated through dividing water displacement by 30s, the pattern of changing temperature's influence on the reaction rate can be summarised.

Hypothesis: If putting the 2-cm-long magnesium ribbon into a reaction flask with 20ml hydrochloric acid in the water bath of temperature 0,10, 20, 30 and 40 degrees celsius for 30 seconds, then, as the temperature increases from 0 to 40, the amount of water displaced because of hydrogen gas emission will increase and as a result, the rate of reaction increases. This is because as temperature rises, particles that participate in the reaction get more kinetic energy, so there will be more chances for effective collision and will break the original chemical bonds more frequently, resulting in a faster rate of reaction. Consequently, temperature and reaction rate will most likely form a complex exponential(non-linear) relationship, as mentioned above.

Variables:

Independent Variable	Range	How it will be changed
Temperature	0, 10, 20, 30, 40 degrees celsius	Heated or iced water will be added to the water bath to change the temperature. The Erlenmeyer flask will be submerged in the water bath to change the temperature of HCl acid, where the reaction takes place. To monitor the instantaneous temperature, a thermometer will be put into the water bath.

Dependent Variable	Units	How it will be measured
Rate of reaction (Hydrogen gas emission)	s^-1	The initial and final water displacement will be recorded by reading off from the eudiometer. The amount of water decreased is the amount of gas emitted. Dividing the volume of gas by the reaction time (30s) is the rate of reaction.

Controlled Variable	How it will be controlled	Why it needs to be controlled

Mass of the Magnesium	The magnesium ribbons are of the same width. The ribbons will be cut into pieces 2 centimetres long.	Magnesium as a reactant needs to stay the same because the amount of magnesium might essentially influence the amount of hydrogen gas generated during the reaction. However, only temperature as an independent variable is investigated.
Concentration of HCl	Only Hydrochloric acid with 1 mol concentration will be selected for the experiment. To achieve this, investigators will only use the liquid from a single container with label "1 mol HCl" on it.	The concentration of one of the reactants, which is HCl acid, affects the rate of reaction. As concentration increases, the rate of reaction increases. To make sure the experiment is only investigating the relationship between temperature of reaction rate, the concentration of HCl needs to be controlled.
Eudiometer	Use the same eudiometer for every experiment.	The scale on the testing tube reveals how much the water is displaced. If a different eudiometer is used, it can be hard to modify and compare the value.
The time of reaction	By using a stopwatch to measure how much the water is displaced in a 30 seconds period.	The longer the magnesium tube stays and reacts in the reaction flask, the more hydrogen gas it will generate and more water will be displaced. To make sure the temperature is the only influence in the experiment, the difference and water displacement caused by different periods of reaction needs to be controlled.
The same reaction flask and rubber stopper with rubber tube	By using the same reaction flask, (wash it after one trial) and the same rubber tube and stopper	To make sure the same air impermeability so that there won't be air from outside pushing the water down that influences the accuracy of the experiment. If different sizes of flasks are used, the amount of time it takes for emitted H2 gas to reach the rubber tube would be different. As the result, some gas might not reach the eudiometer because of the shortened time.

Materials:

- 1×Thermometer
- Tap water (3 buckets)
- Approximately 10 Ice cubes
- 1× Water kettle (for boiling the water)
- 1× Rubber tube (70 cm long)
- 1× Eudiometer (100 ml)
- 1× 250 ml Erlenmeyer Flask
- 2× Rubber stopper (that can connect to rubber tube)
- Hydrochloric acid (1 mol) (60 ml)
- Magnesium Ribbon (one coil)
- 1× Pen and paper (for recording data)
- 1× Plastic water container (30cm by 30cm by 20cm)
- 1× 25 ml graduated cylinder
- 1× funnel
- 6× Gloves
- 3× Lab coats
- 3× Goggles

- 1× Scissors
- 1× Timer
- 1× Pipette
- 1× Stander

Safety Precautions:

Apparatus/Chemical	Possible Hazard	Proper Precautions and/or Disposal
Hydrochloride liquid	During the reaction and transferring of liquid, some might be spilled out into the eyes. When pouring the HCl acid into the reaction flask, hands might contact the liquid. Since HCl is corrosive, it's essentially bad for the human body.	Wear safety goggles to prevent liquid from getting into the eyes. Wear gloves before doing the experiment.
Magnesium ribbon	When holding the magnesium and putting it into the reaction container, hands might be cut by the sharp edge of the metal.	Be careful when holding the magnesium and make sure you don't touch the sharp edge.
Ice	When adding the ice to the water bath, the edge of the ice cube might be sharp and it can potentially cut the hand.	Wear experiment gloves and try not holding the ice with bare hands directly.
Scissors	When cutting the magnesium ribbon into 2-cm pieces, the scissor might potentially cut the finger.	Wear safety gloves and be careful when using the scissor, making sure that the hands are not on top of the magnesium.
Boiling water	When controlling the temperature of the water bath, boiling water will be added to the bath to increase the temperature if necessary. If not careful, hot water might spill on hands, causing scald.	Making sure the pot is kept away from the body when pouring the water. Wearing safety goggles and gloves. Preparing cold water to react instantly if contacting boiling water.
Glassware	Almost all the instruments used are made of glass. During the experiment, they might break into pieces when not being careful, cutting fingers and skin.	When glass breaks, leave the area and clear away the broken glass in a well-protected way. Avoid touching glass with bare hands.

Waste Disposal and reduction

HCl acid	HCl acid needs to be changed for each trial, so there can be potential waste of the material when measuring 20ml of HCl acid.	Pour the acid carefully into the 25ml graduated cylinder. Remove/add the extra liquid with pipette to ensure the accuracy and avoid adding or removing too much liquid.
Magnesium waste	Might affect the lab environment if the waste remained uncleared. People might accidentally cut their fingers when touching the sharp edge of magnesium ribbon waste.	Dispose the wasted magnesium in the waste disposal bin.
Water	Might affect the lab environment if spilled, also	Dispose them into the sink carefully, making sure the

	water resources can be wasted.	water doesn’t get spilled out. To save water, use the same water in the water container for each trial, make sure don’t spill them.
Ice cubes	When they melt at room temperature, they might contaminate the lab environment.	Dispose them into the sink, making sure not to get the hands cut.
Hot water	Might burn skin if spilled onto the skin.	Pour the water into the sink carefully with gloves on, making sure the water drop won’t jump out.
Glassware	might get fingers cut if they break	If they break, make sure to dispose them into the general garbage bin with gloves on.

Procedure:

1. Put on safety goggles, gloves, clear your working space, as well as any other necessary preparations.
2. Fill up the water container with water until it is ¾ full.
3. Pour 20 ml of Hydrochloric acid (1 mol) into the flask carefully, using a funnel.
4. Cut the magnesium into a 2-centimetre piece with scissors and ruler.
5. Put tap water and ice into the water container(30cm by 30cm by 20cm) so that, upon checking the thermometer, the temperature of the water is at 0 degrees celsius. Then fill up the container with the 0 degree celsius water to 600ml in the beaker.
6. Record water temperature by reading off from the thermometer and water level by reading off from the eudiometer. Write down the values in the data collection form.
7. Submerge Erlenmeyer flask containing Hydrochloric acid into the water container so that the top of it is still above water level. If it isn’t, pour out water in sink from the container until it is.
8. Fill the eudiometer with water and place it vertically upright in the water container, with the tip facing up and the entrance facing down. Fix the eudiometer with a stander.
9. Connect the rubber tube to the entrance of the eudiometer. Press the rubber top hard and tightly so that air does not leak out in the gaps.
10. Connect the rubber tube to the rubber stopper. Once again, use duct tape to make sure that they are sealed tightly.
11. Put one tile into the flask, and then immediately plug in the rubber stopper. Start the timer at the same time.
12. After 30 seconds, check the eudiometer and measure the amount of gas in it by reading off the eudiometer. Subtract the initial volume from the final volume to get the water displacement amount. Record the result on paper.
13. Dilute the Magnesium chloride in the waste beaker with a base. Check the acidity of the solution until it reaches 7 pH level. Then pour it down the sink.
14. Repeat the steps three to thirteen four times each for the other temperatures of 10, 20, 30 and 40.
15. Clean all the materials and put them back to where they belong. Dispose the waste in the bins or sink. Use paper towels to clean up the space.

Results: Raw data table:

Table 1: The amount of water in the eudiometer(ml) before and after the chemical reaction of Mg and HCl acid for 30 seconds in temperature of 0, 10, 20, 30, 40 degrees celsius.

	Temperature of HCl (degree celsius)									
	0.0℃		10.0℃		20.0℃		30.0℃		40.0℃	
	Amount of water displaced (amount of H2 gas emitted) (ml)									
	Initial (ml)	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Trial 1	2.1	2.8	1.3	5.5	3.7	21.5	1.4	21.0	4.0	29.0
Trial 2	2.0	7	2.4	8.0	6.1	26.0	4.4	20.0	2.4	26.0
Trial 3	5.4	10	1.7	3.8	0.4	18.5	2.4	19.0	2.4	31.5
Trial 4	4.3	10.2	2.6	6.5	2.4	14.0	1.9	18.0	2.6	20.0

Table 2: The rate of reaction (s^-1) during chemical reaction of Mg and HCl acid in temperature of 0℃, 10℃, 20℃, 30℃, 40℃.

	Temperature of HCl (degree celsius)				
	0.00℃	10. 00℃	20.00℃	30.00℃	40. 00℃
	Rate of reaction (s^-1)				
Trial 1	0.02	0.14	0.59	0.65	0.83
Trial 2	0.17	0.19	0.66	0.52	0.79
Trial 3	0.15	0.07	0.60	0.55	0.97
Trial 4	0.20	0.13	0.39	0.54	0.58
Average	0.14	0.13	0.56	0.57	0.79
Maximum-Minimum /2	0.09	0.06	0.14	0.07	0.20
Coefficient of determination	0.89				

Table 3: Qualitative data of the reaction between Mg and HCl acid after the experiment

Type	Magnesium	HCl acid	H2 gas
Colour	No colour change	No colour change	No colour
Shape	Size diminished	Cannot see obvious change in size	Size increased as more water being displaced
Phase	Solid	Liquid	Gas
State	Floating on HCl acid	Bubbles generated around Magnesium tile	Cannot be described

Sample calculations(water displacement(ml), average water displacement(ml), rate of reaction(ml/s), Max-Min/2)

1. Water displacement in millilitre:
   Data: trial 1, initial 2.1, final 2.8

Calculation: Water displacement(ml): Final-initial=2.8-2.1=0.7ml

2. Rate of reaction (ml/s)
   Data: Trial 1, 0 degree celsius
   Calculation: Rate of reaction (ml/s)=$\frac{Final-initial}{30s} = \frac{2.8-2.1}{30} = 0.02(ml/s)$
3. Average rate of reaction (ml/s)
   Data: trial 1-4, temperature 0 degree celsius
   Calculation: Average rate of reaction=$\frac{T1+T2+T3+T4}{4}$=$\frac{0.02+0.17+0.15+0.20}{4} = 0.14$(ml/s)
4. Max-Min/s
   Date: Trial 1-5, 0 degree celsius
   Calculation: Max-Min/2= $\frac{0.20-0.02}{2} = 0.09$

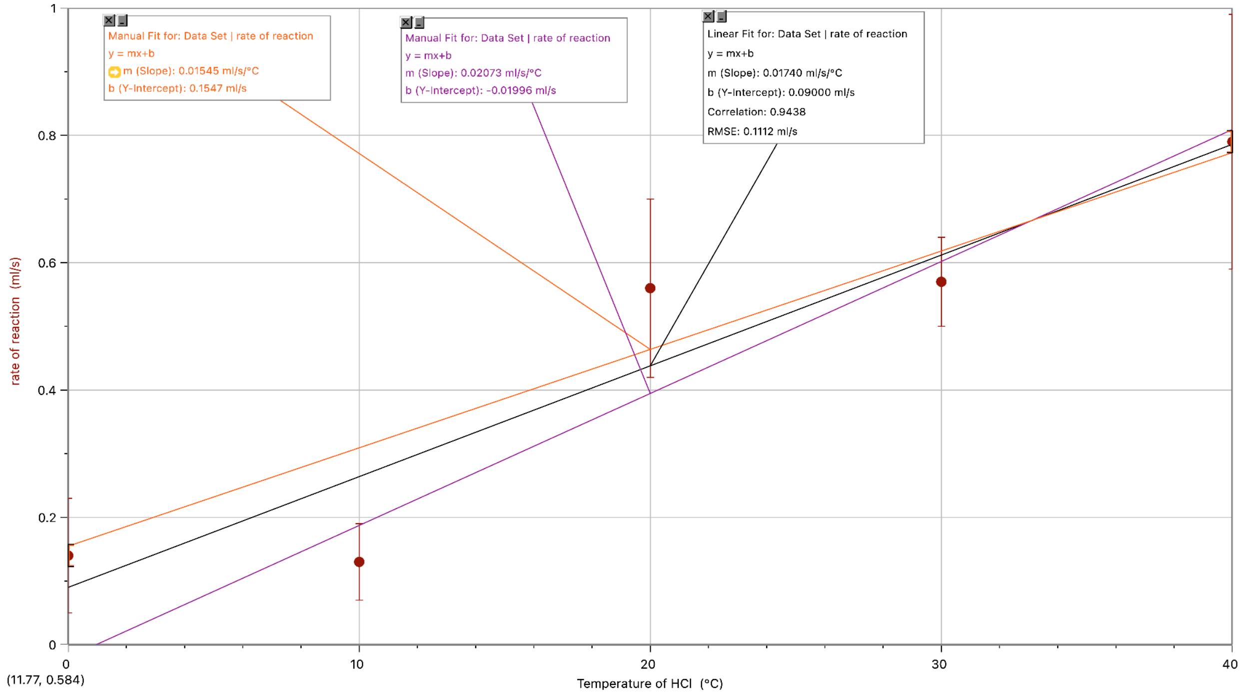
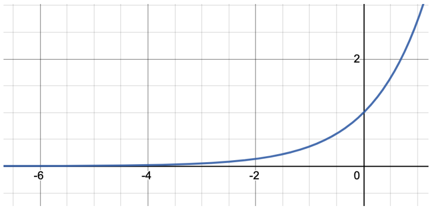


Figure 1- The graph shows the effect of temperature(℃) of HCl on the rate of reaction (s^-1) in the chemical reaction between Mg and HCl acid on the average emission of H2 gas represented by the water displacement in the eudiometer(ml). The graph reveals a positive correlation between temperature and the reaction rate, suggested by the upward trendline and positive slope. However, from temperature 0 to 10 degree celsius, the trend is inaccurate because it was downward sloping.

Conclusion:

Name of statistics	Explanation
Slope and correlation	The slope of the line of best fit in the graph suggests the positive correlation between the increase in temperature and the rate of reaction. The slope of the line of the best fit (0.01740x+0.09) is 0.01740. As the temperature increases by m degree, the reaction rate will increase by 0.0174m (ml/s), as suggested by the mathematical relationship between the independent and dependent variables. The slope is calculated using f(x+h)-f(x)/(h) (h--->0). The R value, representing the correlation, is 0.9438, representing a tight and positive correlation. So, as the temperature increases from 0 to 40 degrees Celsius, the reaction rate also increases. This happens because particles possess more kinetic energy because of increasing temperature, resulting in more effective collisions. As a result, chemical bonds will be broken more frequently, leading to an increase in reaction rate. It fits the collision principle and what is hypothesised: increasing temperature causes an increased rate of reaction, suggesting the validity of the trend and correlation between the independent and dependent variables.
Equation	The equation of the line of the best fit suggests a linear relationship between the independent variable(temperature) and the dependent variable (rate of reaction). There is no clear exponential or other non-linear relations. The expression y=0.0174x+0.09 has a constant as a first-degree derivative. It shows that as

	temperature increases by a particular value in domain 0 to 40, the reaction rate also increases by a particular corresponding proportional value. However, the hypothesis proposed that the temperature and rate of reaction will form a complex exponential relationship that looks like k=Ae^(c/T), where A and c substitute all the constants. It is hard to determine if the data looks more similar to a linear or exponential distribution since the data points are most likely to increase discreetly. The R^2 value suggests a 0.8921 correlation between the line of the best fit and the data, which is acceptable but not excellent. So, only a positive correlation between temperature and rate of reaction can be inferred. The data is not strong enough to determine the specific numerical or mathematical relations when the temperature is from 0 to 40 degrees celsius.
X-intercept	The expression of the line of the best fit suggests an x-intercept at (-5.172, 0). In terms of mathematics, when the temperature is -5.172 degrees Celsius, the reaction rate will be zero. When the reaction rate drops to zero, no particles will be moving. However, this is theoretically impossible because the law of thermodynamics states that all particles will stop moving at 0 kelvin, which is around -273 degrees celsius. At the same time, such a condition is not achievable, as stated in the introduction. Thus, it can be inferred that temperature and the rate of reaction should not follow a strictly linear relationship because every line with a positive slope will intersect the x-axis at a certain point. However, thermodynamics will not allow the reaction rate to reach 0.  The line would be similar to the graph above (just an intuitive example, not numerically accurate), where the line would only approach the x-axis. It reveals that the mathematical relationship between temperature and reaction rate is most likely to follow a complex non-linear relationship(as mentioned in the introduction).
R^2 value	According to the polished data table, the coefficient of determination (R^2 value) is 0.89, suggesting a relatively strong correlation between the points on the graph and the trendline. The more the R^2 value approaches 1, the more reliable and closer the data values are to the line of best fit. The 0.89 R^2 value shows that 89% of the increase in the rate of reaction is due to the changing temperature while the other 11% is due to other factors.

Evaluating the procedure:

The hypothesis states that as temperature increases from 0 degrees celsius to 40 degrees celsius, the amount of water displaced in 30 seconds of reaction time also increases. As a result, the rate of reaction increases. However, from 0 to 10, the reaction rate decreases by 0.01, and from 20 to 30, the reaction rate only increases by 0.01. It should be noted that the rate of reaction will not decrease if the hypothesis is theoretically correct. Moreover, it will not increase only by 0.01 if the relationship between temperature and rate of reaction is linear or exponential. However, the positive correlation between the independent variable and dependent variable fits the hypothesis.

Reliability of results:

The (Max-Min)/2 value shows the variability of data. It describes how far apart data points are distributed around a central value. Usually, larger the (max-min)/2 value means less reliable data collection. For example, at 40 degrees celsius, the (Max-Min)/2 value is 0.2 given by (0.97-0.58)/2. There is a huge gap between the Max and Min value. However, it does not necessarily mean that all of the data is not reliable. For example, at 20 degrees celsius, the (Max-Min)/2 value is 0.14, which is quite high compared to other points. The values for four trials are 0.59, 0.66, 0.60, 0.39. Only the data 0.39 is away from the centre of distribution as the rest of the data stays close together. It shows that only one data of 0.39 is not reliable. Thus, the (Max-Min)/2 is likely to represent possible flaws in data collection, but it cannot show the general reliability of data.

The error bars set the boundaries for how much the data should variate within a range. The upper limit is the top of the error bars, and the bottom represents the lower limit. However, when drawing the max and min lines, they cannot simultaneously go through all the error bars. For example, the max line cannot go through the error bar at 0 and 20 degrees celsius, and the min line is far away from the error bar at 10 degrees celsius. When there is no intersection between the max/min line and the error bars, all the data collected at this point is higher or lower than the limit, which is not trustworthy. The second possibility is that some error bars are too low or too high, making the max/min overly steep or shallow. In this experiment, the data at 10 degrees Celsius makes the max line excessively steep. It shows that the data at these points is not very reliable since it goes beyond the boundary set by the lines or affects the max/min lines drastically.

The dispersion of the data also suggests the unreliability of some of the results. For example, at temperature 0 degrees celsius, three of the trials got values around 0.17 while trial one got 0.02. At the 20 degrees Celsius temperature, three of the trials got values around 0.62 while one trial got 0.39. The considerable difference between these values affects the accuracy of calculating the average value at these temperatures. However, most of the trials and values can be considered accurate due to their high uniformity. For example, at 30 degrees celsius, the results of four trials are 0.65, 0.52, 0.55 and 0.54. The values are not scattering but concentrate on a relatively small range.

Strengths of the method and data:

Firstly, the technical controlled variables are controlled very well. It makes sure the amount of reactant put into the reaction flask is the same for each experiment trial. The Magnesium ribbons are cut into pieces almost strictly 2 centimetres long. If the magnesium tiles were of different lengths, the frequency of effective collision between particles would vary, causing measurement errors or inaccuracy.

Secondly, the reaction time is controlled to strictly 30 seconds for each trial. The timer will be started as soon as the magnesium tile is put into the reaction flask. To make sure the lab partner would read the scale in exactly 30th seconds, someone called out the number of seconds left after 20 seconds of reaction. This close cooperation helps limit the inaccuracy of the experiment caused by time difference since a more extended time would generate more H_2 gas, causing the water level to drop more and making the rate of reaction seem higher than actual.

Lastly, the preparation work is done very well. Before starting the experiment, one lab partner would read the water level on the eudiometer, and the other one would confirm. After writing the initial value down, the experiments would be officially started. The careful reading and preparation help limit the inaccuracy of data collection caused by wrong calculations of water displacement. If the initial value is wrong and not carefully noted, the amount of water displacement would not be precise. In this experiment, such error was limited.

Weaknesses (limitation):

One of the most significant limitations of this experiment is the inadequacy of controlling the independent variable, which is a systematic error. Five temperature values, 0, 10, 20, 30, 40, were determined to be the temperature of HCl acid to investigate the effect of changing temperature on the rate of reaction. Investigators chose to submerge the reaction flask in the water bath to change the temperature of HCl acid. However, firstly, it takes time for the heat of the water to pass to HCl if the water is hotter than HCl, and vice versa. Heat transmission aims to achieve thermal equilibrium. If the outside water is hotter than the HCl acid, then the temperature of water decreases while that of the water increases. So, in this experiment, for example, when the temperature of a water bath is 40 degrees celsius, the actual temperature of HCl acid will be slightly less than 40 degrees, given sufficient time. Nevertheless, the actual temperature control was worse than that. When experimenting, investigators did not put the reaction flask in the water bath long enough for the temperature of HCl to get close to the set value. It takes time to achieve thermal equilibrium, so the conditions for this experiment are not valid enough. Since this problem persists in all of the trials, there is no specific data that supports this limitation.

Secondly, the reading of the eudiometer also lacks accuracy and it is a systematic error. Even though one investigator is calling out the number of seconds past on the timer to remind other investigators to get ready, reading precisely at the 30th second was very difficult since there were bubbles that constantly rose, and the water level was decreasing fast. The absurd low values of reaction rate, 0.13, way lower than expected, at 10 degree celsius can be a result of this. Consequently, only the approximate amount of water displacement could be determined due to reading restrictions of the eudiometer during the experiment.

Due to technical restrictions, investigators cannot manipulate the water bath to be 0 degrees celsius by adding ice to the water, which is a systematic error. The lowest temperature the group can get is around 2 degrees celsius, no matter how much ice is in the water. It can be revealed by the average value of reaction rate at 0 degree celsius, which is 0.14. It is higher than expected according to the line of the best fit. Because of this, the temperature control for the first group of trials is not ideal, and it influences the data collection by causing the rate of reaction to be higher than it should be.

Improvements:

1. Elimination of the temperature inaccuracy caused by heat transmission is hard because it contains complex calculations in thermodynamics. However, investigators could leave the reaction flask with HCl acid in the water bath longer, for around 60 seconds, to let the heat enter the liquid.
2. The best solution to this issue is to use a camera to shoot a photo of the eudiometer at precisely 30 seconds to capture the instant water level. (when one investigator counts down from 5 to 1, the other investigator instantly shoots a photo when he calls out one). Then, they can study the photo to determine a more precise value of water displacement.
3. To best solve this problem, refrigerators can be used. However, due to technical restrictions on high school laboratories, such methods would be impractical.

Extensions to the experiment:

In the experiment, a positive correlation between the increase in temperature and the increase in the reaction rate is inferred. However, the mathematical relationship between them is vague and unsettled. People can also carefully manipulate experimental conditions to develop a conclusive numerical description of the relationship between IV and DV. People can also investigate other factors' effects, such as reactant concentration, on reaction rate. People could more easily manipulate conditions for industrial or other purposes by doing this. In experiments, People should focus on eliminating the deviations on controlled variables and implement ingenious designs to avoid fixable mistakes. People should also use the equipment properly and follow the instructions to prevent inaccuracy caused by improper operation.

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