Experiment design: Reaction rates

Design

Research question: How does the change of the temperature of water (35°C, 45°C, 55°C, 65°C and 75°C) affect the rate of reaction (The speed that NH_4Cl absorbs the heat when it dissociates in water):

$NH_4Cl_{(s)} \longrightarrow NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$

Apparatus required:

1. 1 Beaker (250mL).
2. 1 Cylinder (100mL, ±0.5mL)
3. 1Thermometer(0~100°C, ±0.5°C).
4. 1 Electronic balance (±0.01g).
5. $NH_4Cl_{(s)}$ powder and pan paper.
6. Water
7. 1 Calorimeter.
8. 1 Stopwatch(±0.01s)
9. 1 Iron stand
10. 1 Bunsen burner

Variables:

Independent variables:

The independent variable is the temperature of the water before the $NH_4Cl_{(s)}$ is added into it, and it is controlled by using a Bunsen burner (to heat it).

Dependent variables:

The dependent variable is the temperature change of the aqueous $NH_4Cl_{(s)}$ solution in 5 seconds after adding the $NH_4Cl_{(s)}$into it.

Controlled variables	**Method to control it**
The mass of the $NH_4Cl_{(s)}$.	The mass of the $NH_4Cl_{(s)}$ is controlled to be 5g by using an electronic balance with the uncertainty of ±0.01g.
The volume of water	The volume of the water is controlled to be 75mL by using one 100 ml cylinder with an uncertainty of ±0.5mL.
The surface area of the $NH_4Cl_{(s)}$.	The surface area is controlled by using $NH_4Cl_{(s)}$ powder, which the difference of surface area can be ignored.
The time taken for the experiment	All time lengths will be measured by a stopwatch with an error of ±0.01s and the durations will be controlled for 5 seconds.

The room temperature and pressuremight change during the experiment, but I cannot completely control them. Instead I will run the reaction at the room on the same day to minimize the possible change of room temperature and I will observe the room pressure and temperature by using a thermometerand the pressure meter in the lab before and after the experiment, check if it makes any inconsistence and has any effect on the experiment.

Method to collect data:

1. Check the room pressure and temperature by using the thermometer and pressure meter in the lab.
2. Place the pan paper on the electronic balance (±0.01g) and then measure 5 g of$NH_4Cl_{(s)}$powder using it.
3. Use one 100 ml cylinder (±0.5ml) to measure 75mL water.
4. Transfer water into the beaker (250mL).
5. Put the thermometer (0~100^oC, ±0.5^oC) into the beaker and use the Bunsen burner to heat the water to 35^oC.
6. Transfer the water into the calorimeter.
7. Add the5 g $NH_4Cl_{(s)}$ powder into the calorimeter, which has water (75mL, 35^oC) inside, as fast as I can. Close the lid immediately and start stirring and timing.

   (Before this step is carried out, a trial run should be made in order to see whether the system works appropriately)
8. After the duration 5 seconds, read the change of temperature shown by the thermometer (0~100^oC, ±0.5^oC)and record it down on the paper.
9. Check the room pressure and the room temperature again.
10. Repeat step 1 to 9 for 4 more times with the water being heated to 45^oC, 55^oC, 65^oC and 75^oC, respectively.
11. Repeat the entire experiment for one more time, if time permitting.

The diagram below shows the experiment system:

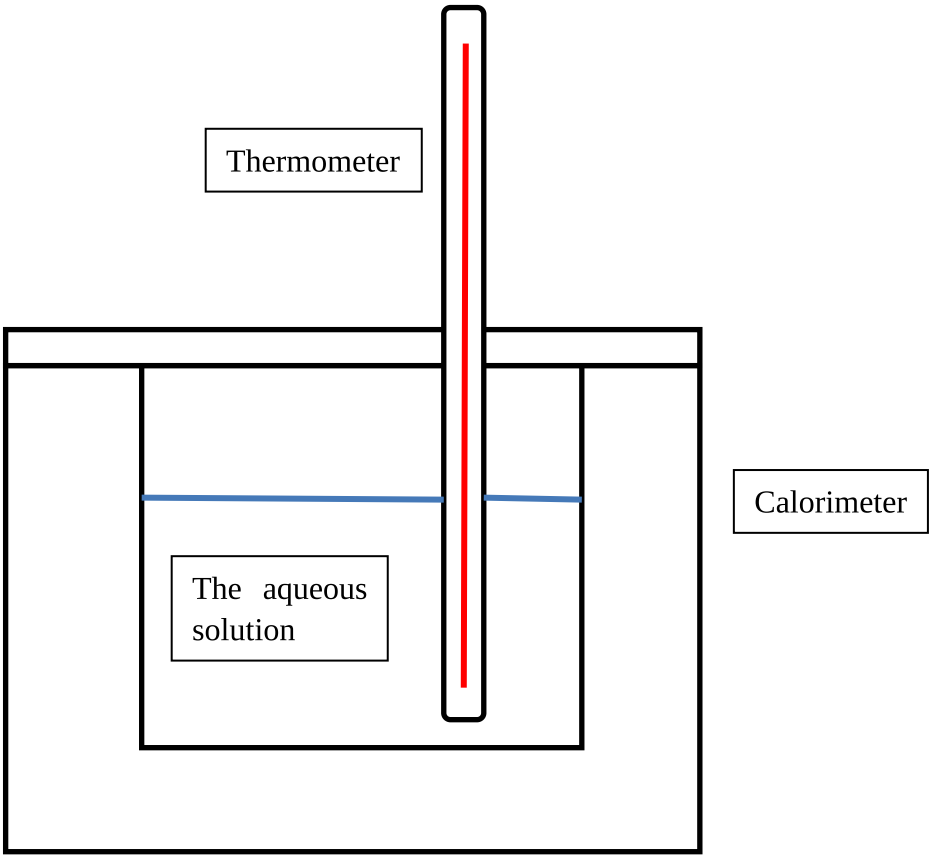


Diagram of the experiment system

Safety:

Safety goggles should be worn during the investigation. Since Bunsen burner is used, students should be aware of the risk of fire burn.

Data collection and processing

Raw data collection:

Room pressure: 102.35 ±0.05kPa

Room temperature: 23.0 ±0.5^{o}C

Table 1: Raw data collection

Run	Initial temperature of water (^{o}C, ±0.5^{o}C)	Final temperature of water (^{o}C, ±0.5^{o}C)	Mass of the $NH_4Cl_{(s)}$ (g, ±0.01g)	Time duration (s, ±0.01s)	Volume of water (mL, ±0.5mL)
1	35.0	34.0	5.00	5.45	75.0
2	45.0	43.0	5.00	5.47	75.0
3	55.0	52.5	5.00	5.38	75.0
4	64.0	61.0	5.00	5.27	75.0
5	75.0	69.0	5.00	5.43	75.0

Qualitative observation:

●$NH_4Cl_{(s)}$ powder is white

●Water is a clear colorless liquid

●Whilst the experiment was running, the reading of the thermometer connected to the calorimeter decreased rapidly, which indicated the reaction is endothermic.

Data processing:

Table 2: Change of the temperature of the solution and the time duration

Run	Initial temperature of water (^oC, $\pm0.5^oC$)	Final temperature of water (^oC, $\pm0.5^oC$)	Change in temperature of water (^oC, $\pm1.0^oC$)	Time duration (s, ±0.01s)
1	35.0	34.0	1.0	5.45
2	45.0	43.0	2.0	5.47
3	55.0	52.5	2.5	5.38
4	64.0	61.0	3.0	5.27
5	75.0	69.0	6.0	5.43

Calculation of the rate of reaction:

Sample calculation: Run 1

Change of temperature during the reaction:

$$\Delta T = |T_{Final} - T_{Initial}| = |34.0 - 35.0| = 1.0℃$$

$$\Delta T_{uncertainty} = 0.5 + 0.5 = 1.0℃$$

Absolute value of the rate of reaction:

$$\frac{\Delta T}{\Delta t} = \frac{1.0}{5.45} = 0.18℃s^{-1}$$

Percentage uncertainty of the temperature:

$$\frac{\Delta T_{uncertainty}}{\Delta T} \times 100\% = \frac{1.0}{1.0} \times 100\% = 100\%$$

Percentage uncertainty of the time:

$$\frac{\Delta t_{uncertainty}}{\Delta t} \times 100\% = \frac{0.01}{5.45} \times 100\% = 0.183\%$$

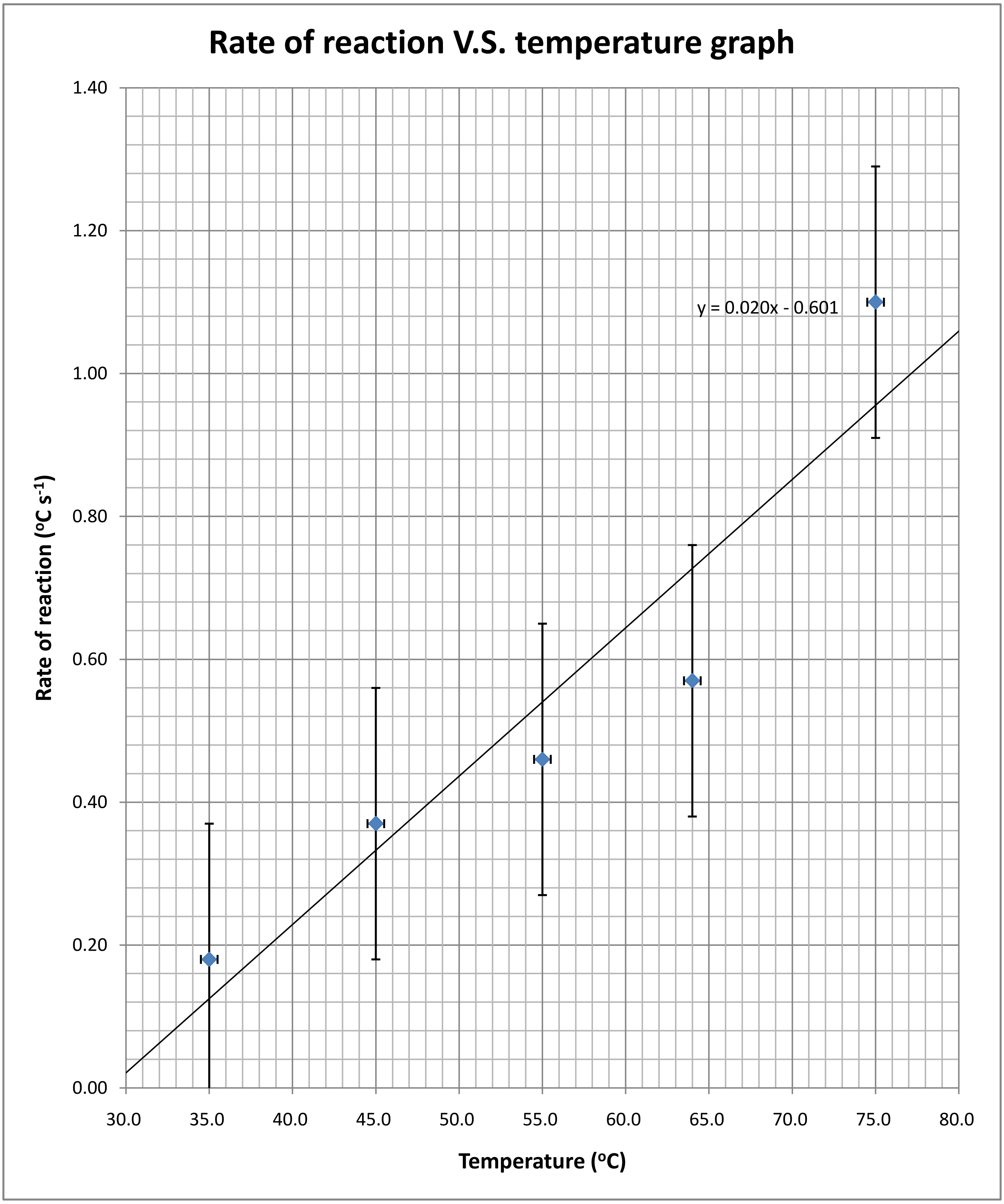
Percentage uncertainty of the rate = $0.183\% + 100\% = 100.183\%$

Absolute uncertainty of the rate = $0.18 \times 100.183\% = 0.18°Cs^{-1}$

Rate of reaction = $0.18°Cs^{-1} \pm 0.18°Cs^{-1}$

Table 3: Processed Data

Run	Initial temperature of water (^{o}C, $\pm 0.5^{o}$C)	Rate of reaction (^{o}C s^{-1})	Absolute uncertainty (^{o}C s^{-1})
1	35.0	0.18	0.18
2	45.0	0.37	0.19
3	55.0	0.46	0.18
4	64.0	0.57	0.19
5	75.0	1.10	0.18



Rate of reaction V.S. temperature graph
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
80.0
y = 0.020x - 0.601
Rate of reaction (°C s⁻¹)
Temperature (°C)

Conclusion and evaluation

Conclusion:

As shown by the graph drawn, when the temperature of the reaction increased, the reaction rate will increase as well. It means that higher temperature will cause higher reaction rates. There are five data points presented in the graph, and a straight best-fit line presenting the trend of the five points. The equation of the best-fit line, which can be obtained from the graph, is $y = 0.0208x - 0.6019$.And therefore we can see that its gradient is positive which means the trend of the rate of reaction is increasing. The best-fit line does not pass through the origin which indicates the rate of reaction is not directly proportional to the temperature, but when there is a temperature change, the rate of reaction would also changes with a ratio of 0.208 to the change in temperature.

In theory, temperature is one of the factors that can affect the rate of reaction. Two reactants will only react if they collide with each other with a minimum energy called activation energy. However, there are only parts of particles which have activation energy. When increasing the temperature, the kinetic energy of particles has also been increased and it means that particles will have higher energy. Therefore, there will be more molecules which have the activation energy which can make the reaction happen.Increasing temperature also increases the rate of collision for a bit, but it is insignificant compared to its effect on the activation energy. Consequently, increase the temperature will slightly increase the frequency of collision, but will lead to a more significant increase in the proportion of molecules which satisfy the requirement of activation energy.From the experiment, it is found that higher the temperature is, more rapidly the heat will be absorbed during the reaction, hence a higher rate of reaction. And according to the graph, there is an increasing trend of the rates of reaction when temperature goes higher.Therefore, they all correspond to the trend stated in the theory and they can be all explained by the theory which increasing temperature affects the proportion of molecules with activation energy. Consequently, we can determine that the result found in the experiment matches with the theory.

There are error bars shown in the graph, indicating the presence of random errors in the experiment. Error bars show ranges of uncertainties in which all values could be possible and accepted. From the graph, we can see that all points are separated besides two sides of the best-fit line and none of them is on the line. However, the best-fit line passes the regions of all error bars, which means with all these uncertainties (random errors) being considered, the result of the experiment can be considered relatively accurate, precise and acceptable.

Evaluation:

The experiment is successful; however it has a variety of errors and mistakes which cause the result and data of it not so precise. From the graph drawn, we can see that there are long error bars, which means that there are large uncertainties. I believe the major error is caused by the uncertainty of the experimental apparatus. When using them during the measurement of the data, their minimum scale is too big for me to collect a precise data. For instance, the minimum scale of the thermometer is $1.0^{o}C$ and the uncertainty is $0.5^{o}C$. When calculating the change in temperature, I use the initial temperature minus final temperature; during the process, its uncertainty is doubled and becomes $1.0^{o}C$. It means that the final result of the temperature change would have an uncertainty of $\pm 1.0^{o}C$.Therefore, since in Run 1 the temperature change is only $1.0^{o}C$ and it has the absolute uncertainty of $\pm 1.0^{o}C$, its percentage uncertainty is 100% which is very big. Besides the uncertainty of the thermometer, there are also other kind of uncertainties caused by the cylinders, the electronic balance and the stopwatch.

Additionally, there are also some systematic errors caused by my experimental skills. For example, Iam not sure that whether there is any heat lost when I opened the lid of the calorimeter and added $NH_4Cl_{(s)}$ powder into it. Besides, I am not sure that I start timing at the same time in the 5 runs since human needs time to react. Moreover, when I was collecting the data from the experiment, there must be some random errors caused by my eyes which made the result imprecise.

Also, the experiment is not very precise and accurate since there is only one set of data. Theoretically, there should be at least two sets of data which could be compared with each other; however, since the time was not permitting, I only did it for one time and collect one set of data.

All those problems need to be improved and the table below shows how to improve them:

Problem discovered in the experiment	**Ways to solve or improve it**
The minimum scale and uncertainty of the experimental apparatus is too big, which might cause the result not as precise as expected.	If possible, change the apparatus that has been used into some other ones which have more precise minimum scales and smaller uncertainties.For example, instead of using a 100 mLcylinder, I can use a 25 mL cylinder since it has a smaller and more precise scale, such as a smallest scale of 0.5 mL instead of 1 mL. If not possible, repeat the readings for two or three more times and take the average value as the final result.
Heat might be lost if the calorimeter is opened when adding the $NH_4Cl_{(s)}$ powder, then the initial temperature is not accurate, and then it might affect the final result. Part of the heat would also be absorbed by calorimeter.	Do these steps much faster so that the small amount of heat lost could be ignored. Or heat the water for longer time and make its temperature higher. Keep a thermometer in the water and monitoring its temperature. Do not close the lid of the calorimeter until the temperature of water reaches the value expected. Then add $NH_4Cl_{(s)}$ powder into it

	and close the lid immediately.Heat absorbed by calorimeter should also be considered when making a conclusion.
It is hard to start the stopwatch immediately after the $NH_4Cl_{(s)}$ powder has been added into the water, so that the time might be inaccurate.	It is almost impossible for someone to add the $NH_4Cl_{(s)}$ powder and start timing at the same time alone. So I can ask for help from my classmates. Let him add the powder and I would start timing immediately.
The experiment only has one set of data and does not have other sets of data to compare with or calculate an average value, which might make the result not general.	Since the major reason of the experiment lasting so long is that the heating process of water takes too much time. Therefore, in order to reduce the time spent on heating process and have more time for recording another set of data, a more powerful burner can be used.