# Aim: To determine how the concentration of each species in a reaction affects the rate of reaction

## Plan

Introduction

In this coursework, the rate of reaction between two reactants will be investigated. Rate of reaction can be defined as the time during which a reactant is lost or a product forms during a chemical reaction. This is calculated by dividing the value of concentration by the time in seconds. There are factors other than concentration that affect the reaction rate, which are temperature, surface area and a catalyst. However, the effect of concentration is the only factor being investigated, meaning that the other factors need to remain constant, and in the absence of any catalyst.

## Theory

Increasing the concentration of a solution increases the reaction rate. This is because there are more particles in the solution, making molecular collisions more likely. Therefore, more collisions between particles take place.

The reaction that will be examined in order to fulfil the aim is the reaction between sodium thiosulphate solution and dilute hydrochloric acid:

$$\mathbf{2HCl_{(aq)} + Na_2S_2O_{3(aq)} \rightarrow 2NaCl_{(aq)} + SO_{2(g)} + S_{(s)} + H_2O_{(l)}}$$

The experiment is carried out by constructing a large cross on a piece of paper, and placing this beneath the reaction mixture. Hydrochloric acid is then mixed together with sodium thiosulphate. The concentration of one of the reactants would change, while the other remains constant, to determine exactly how the concentration affects the rate of reaction. As soon as the two reactants are mixed together, a stopwatch would be started and be stopped as soon as the cross is no longer visible (becomes opaque). This time recorded represents the time taken for the cross to disappear. As both the concentration and reaction time are known, the rate of reaction can be calculated by dividing the concentration by the reaction time. This is achieved by constructing a concentration – time graph, where the gradient at the different concentrations represents the rate of reaction at those concentrations.

Once this has been done, the species that initially had a varying concentration becomes constant, while the other species which had constant concentration now has a varying concentration. The same procedure is then followed.

It then becomes clear exactly how the concentration of each species affects the rate of reaction, which is the aim of this investigation.

Finding the order of reaction

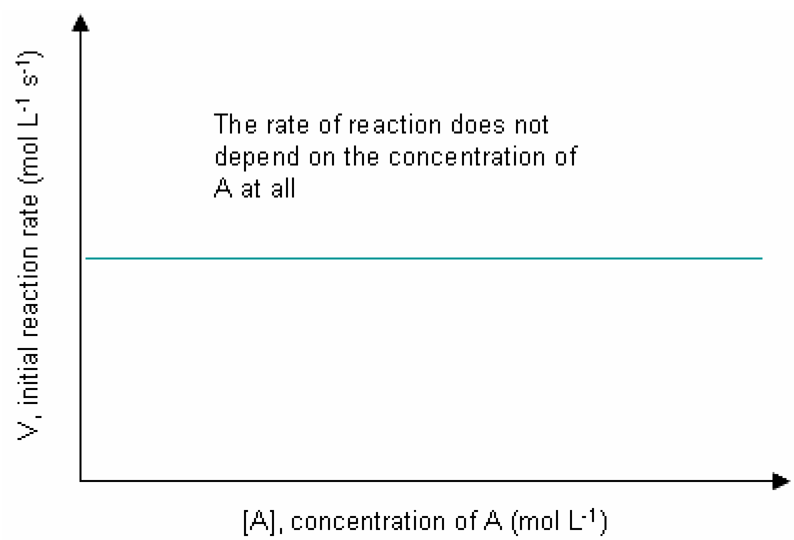
By finding the order of the reaction in regards to each species, the rate equation can be produced. This can be achieved by using the following two methods:

**1) Concentration – Time graph and Initial rate of reaction – Concentration graph**

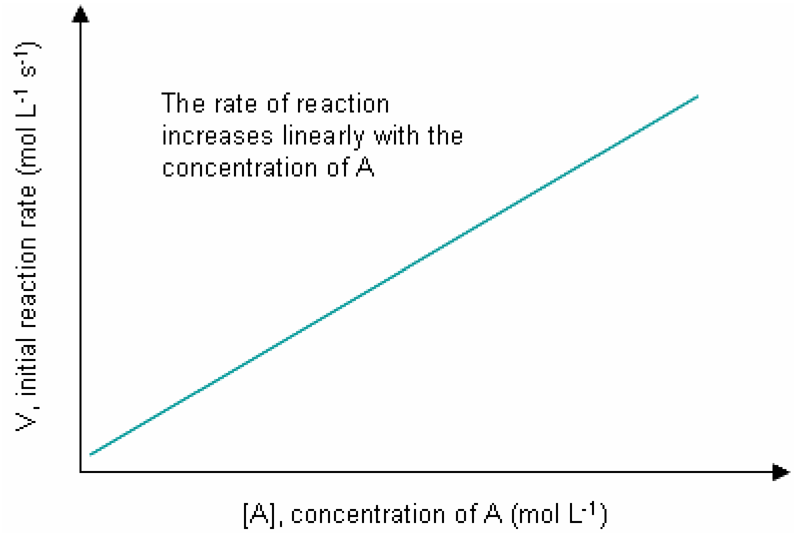
Once the results are collected, a graph of concentration against time is plotted, where the time is the time taken for the cross to disappear from beneath the solution (end of reaction). Straight line tangents are then drawn corresponding to the different concentrations. By calculating the gradient of each of these tangents, the values calculated represent the rate of reaction at those concentrations. On a second graph, these rates of reaction are plotted against the concentration, in order to find the order of reaction with respect to the concentration of that particular species.

The graphs that are produced are then compared to the standard order of reaction graphs for each order. If the graph constructed takes a similar shape to one of these graphs, then it can be assumed that the species has that particular order of reaction. Below are the graphs which differentiate between the three orders of reaction:

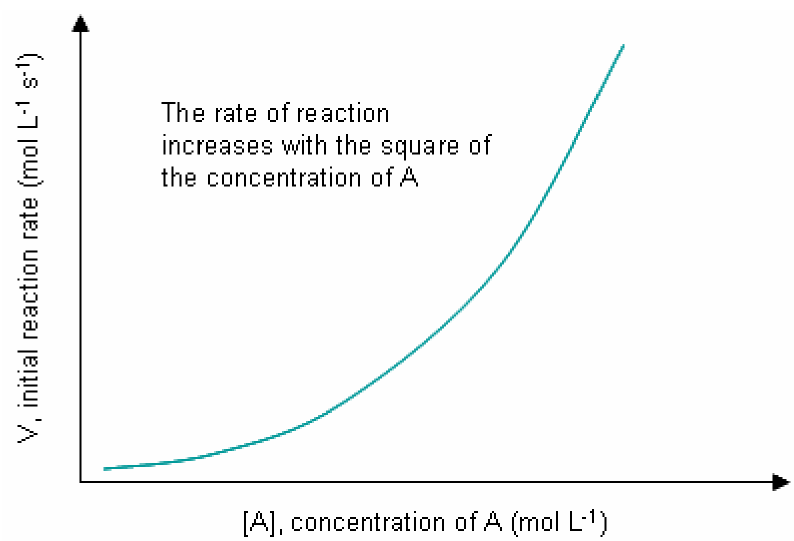
Zero Order



First Order




Second Order




**2) Using rate equation**

For the following reaction:

Rate = $k[HCl]^a[Na_2S_2O_3]^b$

where k = reaction rate constant

a = order of reaction of HCl
b = order of reaction of $Na_2S_2O_3$

Once the order of reaction with respect to the concentration of each species is known, both the value and units of k can be calculated. The rate equation can be used in order to check whether calculations have been correct. When k has been calculated, and the order of reaction with respect to the concentration of each species is known, then substituting concentrations into the rate equation should produce the same rate of reaction that was earlier calculated using the Concentration – Time graph.

**Other methods**

**1) Using the Half-life values**

A Concentration – Time graph has to be plotted for each experiment. The successive half-lives are then calculated, where the half-life is the time taken for the concentration of the species to fall from any chosen value to half that value. The following observations determine which order of reaction is present:

- Half-life is equal to zero – Zero Order reaction

- Successive half-lives are the same – First Order reaction

- Successive half-lives increase – Second Order reaction

Although the use of half-life is a possible method, this is both time consuming and requires a high degree of accuracy. However, comparing the constructed Initial rate of reaction – Concentration graphs with standard graphs is quicker and produces clearer results.

**References:**


- Essential A2 Chemistry for OCR by Ted Lister and Janet Renshaw - pages 99, 100, 101, 102 and 103

- http://www.avogadro.co.uk/kinetics/rate_equation.htm

- Chemistry 2 by Brian Ratcliff and Helen Eccles – pages 108, 109 and 110

- http://www.steve.gb.com/science/kinetics.html


Prediction: The greater the concentration of HCl or $Na_2S_2O_3$, the faster the rate of reaction, meaning that less time is elapsed before the cross disappears from beneath the solution.

Hypothesis: The greater the concentration of either species, the more particles there are in a solution. Therefore, collisions become more likely. More collisions take place, leading to a faster rate of reaction.

Preliminary Test

A preliminary test involved the teacher carrying out the experiment and me watching this. This enabled me to understand exactly how to carry out the experiment and also determine ways in which I would carry out the experiment more accurately. This is vital in order to produce accurate results so that reliable conclusions can be made.

Below are the results:

| **Volume of $Na_2S_2O_3$ (mol dm$^{-3}$)** | **Volume of HCl (cm$^3$)** | **Volume of $H_2O$ (cm$^3$)** | **Total Volume (cm$^3$)** | **Time (seconds)** |
|---|---|---|---|---|
| 50 | 5 | 20 | 75 | 11.51 |

Observations made from the teacher's experiment

Numerous observations were made from the teacher's experiment. He did not initially clean out the beakers and measuring cylinders before carrying out the experiment. This meant that he couldn't claim to be carrying out a fair test, because foreign ions may have damaged and manipulated the results. In addition, when producing the different volumes, the teacher was extremely carefree by not crouching on one knee to get a level table view of the measuring cylinders or double checking the volumes used. This obviously affected the precision at which he carried out the experiment. Also, he didn't test the stopwatch before using them in the experiment which could have meant that false times were produced. The teacher's experiment has also allowed me to realise that there limitations not only on the amount time available, but also the amount of each species that is available.

Finally and most importantly, the teacher didn't use varying concentrations, or repeat the experiment. By not doing this, the teacher was unable to fulfil the aim of this investigation as the affect of concentration on the rate of reaction cannot be determined, and by not repeating the experiment, average readings, which are more accurate than single readings, were not calculated. Again, this obviously affected the both the reliability and accuracy of his experiment.

Preliminary test conclusions

The preliminary test has enabled the following conclusions to be reached about the experiment, which will be utilised when I carry out the final experiment, in order to improve accuracy:

- Need to change the concentration of each species separately
- Need to crouch on one knee to get a level table view of the measuring cylinder, as a high degree of accuracy is required when producing the different concentrations
- Need to double check the volumes used
- Experiment needs to be carried out slowly
- Need to undergo more than one trial for each concentration
- Stopwatch needs to be tested before use
- High degree of accuracy is required when producing the different concentrations
- Cross constructed needs to be extremely large and clear
- Need to know which apparatus is used for each reactant to avoid confusion
- Working space needs to be clear before carrying out the experiment

## Method

Equipment required:

- 3 measuring cylinders – to accurately measure the volumes of HCl, $H_2O$ and $Na_2S_2O_3$
- 0.4 mol $dm^{-3}$ Sodium thiosulphate – reactant needed at different concentrations
- 2 mol $dm^{-3}$ Hydrochloric acid – reactant needed at different concentrations
- Distilled water – used in order to dilute HCl at different concentrations
- Conical flask – to dilute the HCl with $H_2O$
- Beaker – to contain the solution of the reactants

- A4 paper – to be placed beneath the conical flask before the reaction starts

- Marker pen – to construct a large cross on the piece of paper placed beneath the conical flask

- Stopwatch – to time how long it takes for the cross to disappear

Safety Precautions:

- Wear safety goggles – provides protection for eyes

- Wear lab coat – provides protection for clothing

- Wash hands with soap after experiment is finished – in order to remove traces of the chemicals to avoid contamination e.g. of food

- Ensure that work space is clear – in order to prevent human concentration being disturbed during the experiment

- Ensure that equipment containing liquids, e.g. conical flasks, are well away from the edges of the table – in order to prevent the smashing of glassware

- Being as careful as possible when handling chemicals – in order to avoid the spilling of chemicals

- Ensure that surfaces are dry by wiping away any liquids

- Make sure that unwanted products are disposed of in a sink – to prevent accidentally reusing the solution

Ensuring a fair test

In such an experiment, it is vital that a fair test is maintained. This enables accurate results to be produced, and both an accurate and reliable conclusion to be drawn. The following methods are going to be used in order to ensure a fair test:

- Using only one variable per test e.g. changing the concentration of sodium thiosulphate but keeping the concentration of hydrochloric acid constant – this enables an accurate conclusion to be drawn

- Glassware containing the solution will be washed both before use and after measurements – this ensures that results do not become damaged by eliminating ions from the previous trials

- Three trials will be undertaken for each mixture – this enables an accurate average time to be calculated, which reduces the effect of any anomalous results

- Using separate glassware for different reactants – this ensures that the reactants aren't mistakenly mixed together which would produce flawed results

- Resetting the stopwatch after each use – prevents accidentally writing down the incorrect time after the cross disappears

- Keeping the total volume of the solution at 75cm$^3$ as different volumes could produce different results

- Starting the stopwatch as soon as the reactants are in the beaker

Producing different concentrations

In order to determine how each species affects the reaction rate, the concentration of each species needs to be changed, making this a variable. This is achieved by altering the volume of each reactant. However, to accurately determine the effects of concentration, only one reactant can be a variable at a time. By not doing this, the concentrations of both $Na_2S_2O_3$ and HCl are variables, then their effects can not be determined, as it becomes difficult to distinguish between the two variables.

Therefore, in the experiments, the following concentrations will be used, by use of the following volumes:

**Experiment 1**
**Total volume = 75 cm$^3$**

In Experiment 1, the concentration of $Na_2S_2O_3$ is constant, while the concentration of HCl is the independent variable.

Starting concentration of HCl = 2 mol dm$^{-3}$

| **Concentration of HCl (mol dm$^{-3}$)** | **Volume of HCl (cm$^3$)** | **Volume of $H_2O$ (cm$^3$)** | **Volume of $Na_2S_2O_3$ (cm$^3$)** |
|---|---|---|---|
| 2 × (20/100) = **0.40** | 5 × (20/100) = **1** | **24** | **50** |
| 2 × (40/100) = **0.80** | 5 × (40/100) = **2** | **23** | **50** |
| 2 × (60/100) = **1.20** | 5 × (60/100) = **3** | **22** | **50** |
| 2 × (80/100) = **1.60** | 5 × (80/100) = **4** | **21** | **50** |

| | | | |
|---|---|---|---|
| 2 × (100/100) = **2** | 5 × (100/100) = **5** | **20** | **50** |

**<u>Experiment 2</u>**
**Total volume = 75 cm$^3$**

In Experiment 2, the concentration of HCl is constant, while the concentration of $Na_2S_2O_3$ is the independent variable.

Starting concentration of $Na_2S_2O_3$ = 0.4 mol dm$^{-3}$

| Concentration of $Na_2S_2O_3$ (mol dm$^{-3}$) | Volume of $Na_2S_2O_3$ (cm$^3$) | Volume of $H_2O$ (cm$^3$) | Volume of HCl (cm$^3$) |
|---|---|---|---|
| 0.4 × (20/100) = **0.08** | 50 × (20/100) = **10** | **60** | **5** |
| 0.4 × (40/100) = **0.16** | 50 × (40/100) = **20** | **50** | **5** |
| 0.4 × (60/100) = **0.24** | 50 × (60/100) = **30** | **40** | **5** |
| 0.4 × (80/100) = **0.32** | 50 × (80/100) = **40** | **30** | **5** |
| 0.4 × (100/100) = **0.40** | 50 × (100/100) = **50** | **20** | **5** |

**<u>Procedure</u>**

1) Collect required equipment – a conical flask, three measuring cylinders, a piece of A4 paper, a marker pen, a stopwatch and beaker

2) Draw a large cross in the middle of the piece of A4 paper using the marker pen, and place this directly beneath the beaker

3) Accurately measure the following volumes in separate measuring cylinders:

- 50cm$^3$ of $Na_2S_2O_3$
- 1cm$^3$ of HCl
- 24cm$^3$ of $H_2O$

4) Pour the measuring cylinder containing 1$cm^3$ of HCl into the conical flask, followed by the measuring cylinder containing 24$cm^3$ of $H_2O$

5) Pour the measuring cylinder containing 50$cm^3$ of $Na_2S_2O_3$ into the beaker, followed by the conical flask containing the dilute HCl

6) Immediately start the stopwatch

7) Press the stop button on the stopwatch as soon as the cross disappears

8) Write down this time then reset the stopwatch

9) Pour the products in the beaker into a sink, then rinse the conical flask and beaker with tap water

10) Repeat steps 3 – 9 to produce two more sets of results

11) Repeat steps 3 – 10 for the different concentrations/volumes in Experiment 1 and Experiment 2

## Analysing Evidence

Results

**Experiment 1: Concentration of hydrochloric acid is variable; concentration of sodium thiosulphate is constant**

Trial 1

| **Concentration of HCl (mol $dm^{-3}$)** | **Volume of HCl ($cm^3$)** | **Volume of $H_2O$ ($cm^3$)** | **Volume of $Na_2S_2O_3$ ($cm^3$)** | **Time taken for cross to disappear (s)** |
|---|---|---|---|---|
| 0.40 | 1 | 24 | 50 | 31.15 |
| 0.80 | 2 | 23 | 50 | 18.82 |
| 1.20 | 3 | 22 | 50 | 15.98 |
| 1.60 | 4 | 21 | 50 | 14.80 |
| 2.00 | 5 | 20 | 50 | 14.43 |

Trial 2

| **Concentration of HCl (mol $dm^{-3}$)** | **Volume of HCl ($cm^3$)** | **Volume of $H_2O$ ($cm^3$)** | **Volume of $Na_2S_2O_3$ ($cm^3$)** | **Time taken for cross to disappear (s)** |
|---|---|---|---|---|
| 0.40 | 1 | 24 | 50 | 29.73 |
| 0.80 | 2 | 23 | 50 | 19.68 |
| 1.20 | 3 | 22 | 50 | 16.96 |
| 1.60 | 4 | 21 | 50 | 15.05 |
| 2.00 | 5 | 20 | 50 | 13.19 |

Trial 3

| Concentration of HCl (mol dm$^{-3}$) | Volume of HCl ($cm^3$) | Volume of $H_2O$ ($cm^3$) | Volume of $Na_2S_2O_3$ ($cm^3$) | Time taken for cross to disappear (s) |
|---|---|---|---|---|
| 0.40 | 1 | 24 | 50 | 19.01 |
| 0.80 | 2 | 23 | 50 | 16.12 |
| 1.20 | 3 | 22 | 50 | 12.18 |
| 1.60 | 4 | 21 | 50 | 11.98 |
| 2.00 | 5 | 20 | 50 | 9.82 |

**Test 2: Concentration of sodium thiosulphate is variable; concentration of hydrochloric acid is constant**

Trial 1

| Concentration of $Na_2S_2O_3$ (mol dm$^{-3}$) | Volume of $Na_2S_2O_3$ ($cm^3$) | Volume of HCl ($cm^3$) | Volume of $H_2O$ ($cm^3$) | Time taken for cross to disappear (s) |
|---|---|---|---|---|
| 0.08 | 10 | 5 | 60 | 55.87 |
| 0.16 | 20 | 5 | 50 | 27.66 |
| 0.24 | 30 | 5 | 40 | 19.46 |
| 0.32 | 40 | 5 | 30 | 14.22 |
| 0.40 | 50 | 5 | 20 | 10.68 |

Trial 2

| **Concentration of $Na_2S_2O_3$ (mol $dm^{-3}$)** | **Volume of $Na_2S_2O_3$ ($cm^3$)** | **Volume of HCl ($cm^3$)** | **Volume of $H_2O$ ($cm^3$)** | **Time taken for cross to disappear (s)** |
|---|---|---|---|---|
| 0.08 | 10 | 5 | 60 | 61.93 |
| 0.16 | 20 | 5 | 50 | 30.18 |
| 0.24 | 30 | 5 | 40 | 18.09 |
| 0.32 | 40 | 5 | 30 | 12.87 |
| 0.40 | 50 | 5 | 20 | 9.96 |

Trial 3

| **Concentration of $Na_2S_2O_3$ (mol $dm^{-3}$)** | **Volume of $Na_2S_2O_3$ ($cm^3$)** | **Volume of HCl ($cm^3$)** | **Volume of $H_2O$ ($cm^3$)** | **Time taken for cross to disappear (s)** |
|---|---|---|---|---|
| 0.08 | 10 | 5 | 60 | 58.12 |
| 0.16 | 20 | 5 | 50 | 28.37 |
| 0.24 | 30 | 5 | 40 | 18.32 |
| 0.32 | 40 | 5 | 30 | 13.78 |
| 0.40 | 50 | 5 | 20 | 10.01 |

**Average time taken in Experiment 1**

| **Concentration of HCl (mol dm$^{-3}$)** | **Volume of HCl (cm$^3$)** | **Volume of $H_2O$ (cm$^3$)** | **Volume of $Na_2S_2O_3$ (cm$^3$)** | **Total of times (s)** | **Average time taken for cross to disappear (Total of times / 3) (s)** |
|---|---|---|---|---|---|
| 0.40 | 1 | 24 | 50 | 79.89 | **26.63** |
| 0.80 | 2 | 23 | 50 | 54.62 | **18.21** |
| 1.20 | 3 | 22 | 50 | 45.12 | **15.04** |
| 1.60 | 4 | 21 | 50 | 41.83 | **13.94** |
| 2.00 | 5 | 20 | 50 | 37.44 | **12.48** |

**Average time taken in Experiment 2**

| **Concentration of $Na_2S_2O_3$ (mol dm$^{-3}$)** | **Volume of $Na_2S_2O_3$ (cm$^3$)** | **Volume of HCl (cm$^3$)** | **Volume of $H_2O$ (cm$^3$)** | **Total of times (s)** | **Average time taken for cross to disappear (Total of times / 3) (s)** |
|---|---|---|---|---|---|
| 0.08 | 10 | 5 | 60 | 175.92 | **58.64** |
| 0.16 | 20 | 5 | 50 | 86.21 | **28.74** |
| 0.24 | 30 | 5 | 40 | 55.87 | **18.62** |
| 0.32 | 40 | 5 | 30 | 40.87 | **13.62** |
| 0.40 | 50 | 5 | 20 | 30.65 | **10.22** |

Calculating rate of reaction

As mentioned earlier, the rate of reaction is calculated by dividing the concentration of a species by the time taken for the cross to disappear. Below are these calculations:

Experiment 1

| Concentration of HCl ($mol\ dm^{-3}$) | Gradient | Initial rate of reaction ($mol\ dm^{-3}\ s^{-1}$) |
|---|---|---|
| 0.400 | = 0.240 / 7.500 | **0.032** |
| 0.800 | = 0.400 / 6.500 | **0.062** |
| 1.200 | = 0.453 / 3 | **0.151** |
| 1.600 | = 0.427 / 1 | **0.427** |
| 2.000 | = 0.507 / 1 | **0.507** |

Experiment 2

| Concentration of $Na_2S_2O_3$ ($mol\ dm^{-3}$) | Gradient | Initial rate of reaction ($mol\ dm^{-3}\ s^{-1}$) |
|---|---|---|
| 0.080 | = 0.021 / 15 | **$1.422\times10^{-3}$** |
| 0.160 | = 0.075 / 17 | **$4.392\times10^{-3}$** |
| 0.240 | = 0.075 / 6 | **0.012** |
| 0.320 | = 0.112 / 6 | **0.019** |
| 0.400 | = 0.101 / 3 | **0.034** |

Now that the initial rate of reaction at each concentration is known, the initial rate of reaction – concentration graph for each species can be constructed, and after this the order of reaction can be determined.

## Interpreting initial rate of reaction – concentration graphs

As pointed out earlier in this coursework, the order of reaction for each species can be determined by comparing the initial rate of reaction – concentration graph with the three standard initial rate of reaction – concentration graphs, for the three different orders of reaction. Below are the conclusions:

Experiment 1

The curve produced is most similar to the second order graph. Therefore the concentration of HCl is of second order.

Experiment 2

The curve produced is most similar to the second order graph. Therefore the concentration of $Na_2S_2O_3$ is of second order.

## Determining the rate equation

As the concentration of HCl and $Na_2S_2O_3$ are both of second order, the rate equation is the following:

$$\text{Rate} = k[HCl]^2[Na_2S_2O_3]^2$$

Units of k

With the full rate equation known, the units of the constant k can be calculated:

$\text{Rate} = k[HCl]^2[Na_2S_2O_3]^2$

$\text{mol dm}^{-3}\text{ s}^{-1} = k\ (\text{mol dm}^{-3})^2\ (\text{mol dm}^{-3})^2$

$\text{mol dm}^{-3}\text{ s}^{-1} = k\ (\text{mol}^2\text{ dm}^{-6})\ (\text{mol}^2\text{ dm}^{-6})$

$\text{mol dm}^{-3}\text{ s}^{-1} = k\ (\text{mol}^4\text{ dm}^{-12})$

$k = \text{mol dm}^{-3}\text{ s}^{-1} / \text{mol}^4\text{ dm}^{-12}$

Therefore, $k = \text{mol}^{-3}\text{ dm}^9\text{ s}^{-1}$

# Evaluation

I confidently believe that my initial prediction has been justified. From both initial rate of reaction – concentration graphs constructed for each experiment, it is obvious that as the concentration of the species increases, the rate of reaction also increases. The order of reaction in regard to each species has also been determined. However, I have experienced both procedural errors and errors in measurement. Below are these errors and ways in which I could overcome these if repeating the experiment:

## Procedural errors

| Procedural error | Modification to method |
| --- | --- |
| Having to mix the solutions, starting the stopwatch immediately and stopping the stopwatch as soon as the cross disappears | One person would be in charge of producing different concentrations and mixtures, one person would be in charge of timing and one person would be in charge of determining when the cross disappears |
| Foreign ions damaging the results | One person would be in charge of washing apparatus after use |
| Temperature could have affected the results as it is not controlled | Carry out all of the experiments on the same day to ensure constant conditions i.e. room temperature |

## Errors in measurement

| Errors in measurement | Modification to method |
| --- | --- |
| Producing accurate and correct times from the stopwatch | Ensure that the stopwatch functions properly, reset the stopwatch before use, slowly copy the time on the stopwatch after the reaction is complete and then compare the time written down with the time on the stopwatch |
| Using accurate volumes of the reactants | Slowly measure the amount of reactant that is required, take the meniscus into account as the starting point, crouch down for a view from table level to ensure the correct volume and ensure this is poured directly into the reaction beaker and not onto the sides of the beaker |

The main source of error in my investigation was obviously measuring the time taken for the cross to disappear. I found it difficult trying to start the stopwatch immediately after the reactants were mixed. Also, it was surprisingly a challenge to determine when the cross had completely disappeared as in some cases a small part of the cross was still visible from some angles. Although I feel that measurements taken have been quite accurate, these factors clearly affected the accuracy of my results.

In order to reduce the effect of all these errors, I would do the following if repeating this experiment:

- Have five trials instead of three – in order to produce more accurate average times

- Use different beakers for the reaction mixture if there was a greater amount of equipment available – in order to avoid effect of foreign ions

- Extensive cleaning of apparatus before use – the apparatus could have been contaminated before use which would produce inaccurate results