Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

Part B - To study the effect of temperature on the rate of a reaction.

Part C - To study the effect of a catalyst on the rate of a reaction.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

Iodine clock Reaction

$$S_2O_8^{2-}\,(aq) + 2\,I^-\,(aq) \rightarrow 2\,SO_4^{2-}\,(aq) + I_2\,(aq)$$

(⟵ clear solution ⟶) (⟵ pale yellow solution ⟶)

Reactants:

Ammonium persulfate	$(NH_4)_2S_2O_8$
Potassium iodide	KI

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

How do we do this?

Iodine clock Reaction

$$S_2O_8^{2-}\,(aq) + 2\,I^-\,(aq) \rightarrow 2\,SO_4^{2-}\,(aq) + I_2\,(aq)$$

(⟵ clear solution ⟶) (⟵ pale yellow solution ⟶)

Observe a COLOUR CHANGE!

Problem: The pale yellow solution is visually very difficult to judge.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2 , and therefore, determine the reaction's rate law.

How do we do this?

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$

(⟵ clear solution ⟶) (⟵ pale yellow solution ⟶)

Introduce two substances to help us observe the colour change more accurately:

1. Starch indicator
2. Sodium thiosulfate, $Na_2S_2O_3$, of a fixed quantity

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

We time how long it takes for the solution to turn colour.

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq) \qquad (1)$$

(clear solution)

$$I_2(aq) + 2\,S_2O_3^{2-}(aq) \longrightarrow S_4O_6^{2-}(aq) + 2\,I^-(aq) \qquad (2)$$

thiosulfate ion

$$I_2(aq) + \text{starch} \longrightarrow \text{iodine-starch complex} \qquad (3)$$

(coloured solution)

As the I_2 is formed (1), it reacts with the fixed amount of sodium thiosulfate that has been added to the reaction mixture (2). When the sodium thiosulfate is used up, the next quantity of I_2 that is formed reacts with the starch indicator to form a colour complex, and turns the clear solution into a coloured solution (3).

Reaction Kinetics

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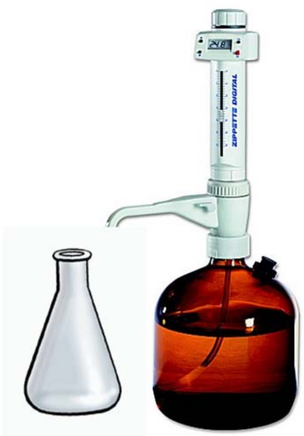
Make solutions of different concentrations.

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$



Prepare 14 solutions in 14 Erlenmeyer flasks with different concentrations of $S_2O_8^{2-}$ and I^- solutions!

Label them:

A1, A2, A3, A4, A5, A6, A7.

B1, B2, B3, B4, B5, B6, B7.

SEPARATE the reactants until we are ready to mix them!

KI (I^-) in 'A' solutions; $(NH_4)_2S_2O_8$ ($S_2O_8^{2-}$) in 'B' solutions

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Total volume of 'A' solutions =

30.0 mL

Experiment 2: Factors Affecting Reaction Rates

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$

Table (2-2) - Contents of the seven 'A' solutions.

SOLUTION	0.00500 M $Na_2S_2O_3$ (mL)	0.200 M KI (mL)	distilled H_2O (mL)	3 % starch indicator
A1	10.0	20.0	0.0	3 drops
A2	10.0	20.0	0.0	3 drops
A3	10.0	20.0	0.0	3 drops
A4	10.0	20.0	0.0	3 drops
A5	10.0	15.0	5.0	3 drops
A6	10.0	10.0	10.0	3 drops
A7	10.0	5.0	15.0	3 drops

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Total volume of 'B' solutions =

20.0 mL

Experiment 2: Factors Affecting Reaction Rates

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$

Table (2-3) – Contents of the seven 'B' solutions.

SOLUTION	0.100 M $(NH_4)_2S_2O_8$ (mL)	distilled H_2O (mL)
B1	5.0	15.0
B2	10.0	10.0
B3	15.0	5.0
B4	20.0	0.0
B5	20.0	0.0
B6	20.0	0.0
B7	20.0	0.0

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Total volume of the combined solution =

50.0 mL

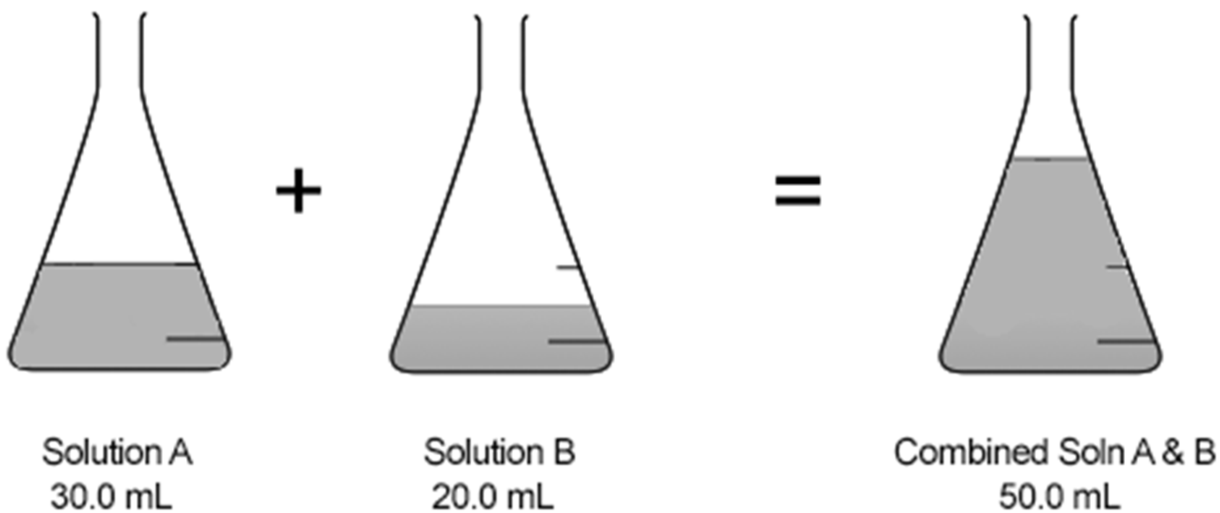
Experiment 2: Factors Affecting Reaction Rates

Iodine clock Reaction

$$S_2O_8^{2-}\,(aq) + 2\,I^-\,(aq) \rightarrow 2\,SO_4^{2-}\,(aq) + I_2\,(aq)$$

MIX and TIME:

A1 + B1	A2 + B2	A3 + B3	A4 + B4	A5 + B5	A6 + B6	A7 + B7
(expt 1)	(expt 2)	(expt 3)	(expt 4)	(expt 5)	(expt 6)	(expt 7)



Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

When solutions A1 and B1 are combined, what is the concentration of $(NH_4)_2S_2O_8$ in moles/L?

SOLUTION	0.100 M $(NH_4)_2S_2O_8$ (mL)	distilled H_2O (mL)
B1	5.0	15.0

(0.0050 L) x (0.100 moles/L) = 0.00050 moles $(NH_4)_2S_2O_8$

$$\frac{0.00050 \text{ moles } (NH_4)_2S_2O_8}{0.0500 \text{ L}} = 0.010 \text{ M } (NH_4)_2S_2O_8$$

in the combined A1 + B1 solution

Total volume of the combined solution = 50.0 mL

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Follow the example on the previous slide and calculate the concentrations of $(NH_4)_2S_2O_8$ in moles/L when A2+B2, A3+B3, A4+B4, A5+B5, A6+B6 and A7+B7 are combined?

SOLUTION	0.100 M $(NH_4)_2S_2O_8$ (mL)
B1	5.0
B2	10.0
B3	15.0
B4	20.0
B5	20.0
B6	20.0
B7	20.0

(0.0050 L) x (0.100 moles/L) = 0.00050 moles $(NH_4)_2S_2O_8$

$$\frac{0.00050 \text{ moles } (NH_4)_2S_2O_8}{0.0500 \text{ L}} = \mathbf{0.010\ M\ \ (NH_4)_2S_2O_8}$$

Note: The concentrations of $(NH_4)_2S_2O_8$ should be the same for the A4/B4, A5/B5, A6/B6 and A7/B7 solutions because the B4, B5, B6, and B7 solutions each contains 20.0 mL of $(NH_4)_2S_2O_8$.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Follow the example on the previous slide and calculate the concentrations of $(NH_4)_2S_2O_8$ in moles/L when A2+B2, A3+B3, A4+B4, A5+B5, A6+B6 and A7+B7 are combined?

Enter concentrations in Table 2-4 and Table 2-6 in the post-lab questions of Experiment 2.

Note: The concentrations of $(NH_4)_2S_2O_8$ should be the same for the A4/B4, A5/B5, A6/B6 and A7/B7 solutions.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

When solutions A1 and B1 are combined, what is the concentration of KI in moles/L?

SOLUTION	0.00500 M $Na_2S_2O_3$ (mL)	0.200 M KI (mL)	distilled H_2O (mL)	3 % starch indicator
A1	10.0	20.0	0.0	3 drops

(0.0200 L) x (0.200 moles/L) = 0.00400 moles KI

$$\frac{0.00400 \text{ moles KI}}{0.0500\text{L}} = 0.0800 \text{ M KI}$$

in the combined A1 + B1 solution

Total volume of the combined solution =

50.0 mL

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Follow the example on the previous slide and calculate the concentrations of KI in moles/L when A2+B2, A3+B3, A4+B4, A5+B5, A6+B6 and A7+B7 are combined?

SOLUTION	0.200 M KI (mL)
A1	20.0
A2	20.0
A3	20.0
A4	20.0
A5	15.0
A6	10.0
A7	5.0

(0.0200 L) x (0.200 moles/L) = 0.00400 moles KI

$$\frac{0.00400 \text{ moles KI}}{0.0500\text{L}} = 0.0800 \text{ M KI}$$

Note: The concentrations of KI should be the same for the A1/B1, A2/B2, A3/B3 and A4/B4 solutions because the A1, A2, A3, and A4 solutions each contains 20.0 mL of KI.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Follow the example on the previous slide and calculate the concentrations of KI in moles/L when A2+B2, A3+B3, A4+B4, A5+B5, A6+B6 and A7+B7 are combined?

Enter concentrations in Table 2-4 and Table 2-6 in the post-lab questions of Experiment 2.

Note: The concentrations of KI should be the same for the A1/B1, A2/B2, A3/B3 and A4/B4 solutions .

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

How many moles of $Na_2S_2O_3$ are available?

SOLUTION	0.00500 M $Na_2S_2O_3$ (mL)
A1	10.0
A2	10.0
A3	10.0
A4	10.0
A5	10.0
A6	10.0
A7	10.0

(0.0100 L) x (0.00500 moles/L)
= 0.0000500 moles $Na_2S_2O_3$

This is the same amount of $Na_2S_2O_3$ that is added to ALL the 'A' solutions.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Iodine clock Reaction

$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$ (1)

(← clear solution →)

$\underline{1}\,I_2(aq) + \underline{2}\,S_2O_3^{2-}(aq) \longrightarrow S_4O_6^{2-}(aq) + 2\,I^-(aq)$ (2)

thiosulfate ion (← clear solution)→

How many moles of I_2 will consume the $Na_2S_2O_3$ added?

From the previous slide, we calculated that there is 0.0000500 moles $Na_2S_2O_3$ in each 'A' solution.

From equation (2), the I_2 and $S_2O_3^{2-}$ is 1:2.

It takes 0.0000500/2 = 0.0000250 moles of I_2 to consume the $S_2O_3^{2-}$.

Experiment 2: Factors Affecting Reaction Rates

What is the concentration of I_2 when the $Na_2S_2O_3$ is consumed?

From the previous slide, we calculated that it takes 0.0000250 moles of I_2 to consume the $S_2O_3^{2-}$.

$$\frac{0.0000250 \text{ moles } I_2}{0.0500 L} = 0.000500 \text{ M } I_2$$

Total volume of the combined solution = **50.0 mL**.

When you time how long it takes for the solution to turn colour, you are actually timing how long it takes to produce 0.000500 M I_2 !!!

Remember this number. You'll need the $[I_2]$ in the rate calculation.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2, and therefore, determine the reaction's rate law.

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$

(⟵ clear solution ⟶) (⟵ pale yellow solution ⟶)

What is a reaction's rate law?

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

What is a reaction's rate law?

Iodine clock Reaction

$$S_2O_8^{2-}\,(aq) + 2\,I^-\,(aq) \rightarrow 2\,SO_4^{2-}\,(aq) + I_2\,(aq)$$

The rate law for a chemical reaction is an experimentally determined mathematical equation that describes the progress of the reaction.

For the Iodine clock reaction, the reaction rate of formation of I_2 is proportional to the product of the concentrations each reactant each raised to some power, *x* and *y*.

$$\text{Rate} \propto [S_2O_8^{2-}]^x\,[I^-]^y$$

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

What is a reaction's rate law?

Iodine clock Reaction

$$S_2O_8^{2-}(aq) + 2\,I^-(aq) \rightarrow 2\,SO_4^{2-}(aq) + I_2(aq)$$

$$\text{Rate} \propto [S_2O_8^{2-}]^x\,[I^-]^y$$

We can remove the proportional symbol and introduce a proportionality constant, *k*.

$$\text{Rate} = k\,[S_2O_8^{2-}]^x\,[I^-]^y$$

The proportionality constant, *k*, is known as the rate constant.

We will experimentally determine the values of *x* and *y*.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part A - To determine the effect of concentration on the rate of formation of Iodine, I_2 , and therefore, determine the reaction's rate law.

Table 2-4 Sample Calculation

Experiment	Solution	Time (sec)	$[S_2O_8^{2-}]$ (moles/L)	$[I^-]$ (moles/L)	Rate of formation of I_2 (moles/L)
1	A1/B1	264*	0.0100	0.0800	

* Sample data

$$\text{Rate of formation of } I_2 = \frac{[I_2]\text{ formed}}{\text{time}} = \frac{0.000500\text{ M}}{264\text{ s}} = 1.89 \times 10^{-6}\text{ M/s}$$

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Table 2-4 Sample Calculation

Experiment	Solution	Time (sec)	$[S_2O_8^{2-}]$ (moles/L)	$[I^-]$ (moles/L)	Rate of formation of I_2 (moles/L)
1	A1/B1	264	0.0100	0.0800	1.89×10^{-6}
2	A2/B2	122*	0.0200		4.09×10^{-6}

* Sample data

Similarly, we can calculate the Rate of formation of I_2 for expt 2.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Table 2-5 Sample Calculation of '*x*'

Experiment pairs	'*x*', the order of the reaction with respect to $[S_2O_8^{2-}]$	Average value of '*x*'
1 and 2		

$$\text{Rate} = k\,[S_2O_8^{2-}]^x\,[I^-]^y$$

Expt 1:

Expt 2:

$$\frac{1.89 \times 10^{-6}}{4.09 \times 10^{-6}} = \frac{k\,[S_2O_8^{2-}]^x[I^-]^y}{k\,[S_2O_8^{2-}]^x[I^-]^y} = \frac{k(0.0100)^x(0.0800)^y}{k(0.0200)^x(0.0800)^y}$$

$$0.464 = \left(\frac{1}{2}\right)^x$$

$0.464 = 0.5^x$

$X = 1.11$

Reaction Kinetics

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Experiment 2: Factors Affecting Reaction Rates

Similar calculation can be carried out to calculate '*y*' for Table 2-7.

$$\text{Rate} = k\,[S_2O_8^{2-}]^{x}\,[I^-]^{y}$$

'*x*' is the "order of the reaction with respect to $S_2O_8^{2-}$"

'*y*' is the "order of the reaction with respect to I^-"

'*x + y*' is the "overall order of the reaction"

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Once 'x' and 'y' are determined, we can calculate the rate constant, k.

Table 2-9 Sample Calculation

Experiment	Rate constant, k	Average value of k
1		

$$1.89 \times 10^{-6} = k\,(0.0100)^x\,(0.0800)^y$$

Substitute 'x' and 'y' and solve for k.

Reaction Kinetics

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Experiment 2: Factors Affecting Reaction Rates

Objective: Part B - To study the effect of temperature on the rate of a reaction.

How do we do this?

Keep the concentrations of the reactants constant, but let the Reaction react at different temperatures:

0^oC, 20^oC, 30^oC, 40^oC

Use A4, B4 solutions for all the temperatures!!

Part B calculations for Table 2-10 is similar to Part A.

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part B - To study the effect of temperature on the rate of a reaction.

Verify Arrhenius' Equation

$$k = Ae^{-\frac{E_{act}}{RT}}$$

A is the pre-exponential or frequency factor, a constant related to the collision frequency
R is the gas constant (8.314 J / K mole)
T is the absolute temperature (K)
k is the rate constant at temperature T
$\boldsymbol{E_{act}}$ is the activation energy, the energy required by the reacting species for their collisions to be effective (ie - those that lead to the formation of products)

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part B - To study the effect of temperature on the rate of a reaction.

Rewrite Arrhenius' Equation

$$k = Ae^{-\frac{E_{act}}{RT}} \quad \Rightarrow \quad \ln k = -\frac{E_{act}}{R}\left(\frac{1}{T}\right) + \ln A$$

y = m x + b

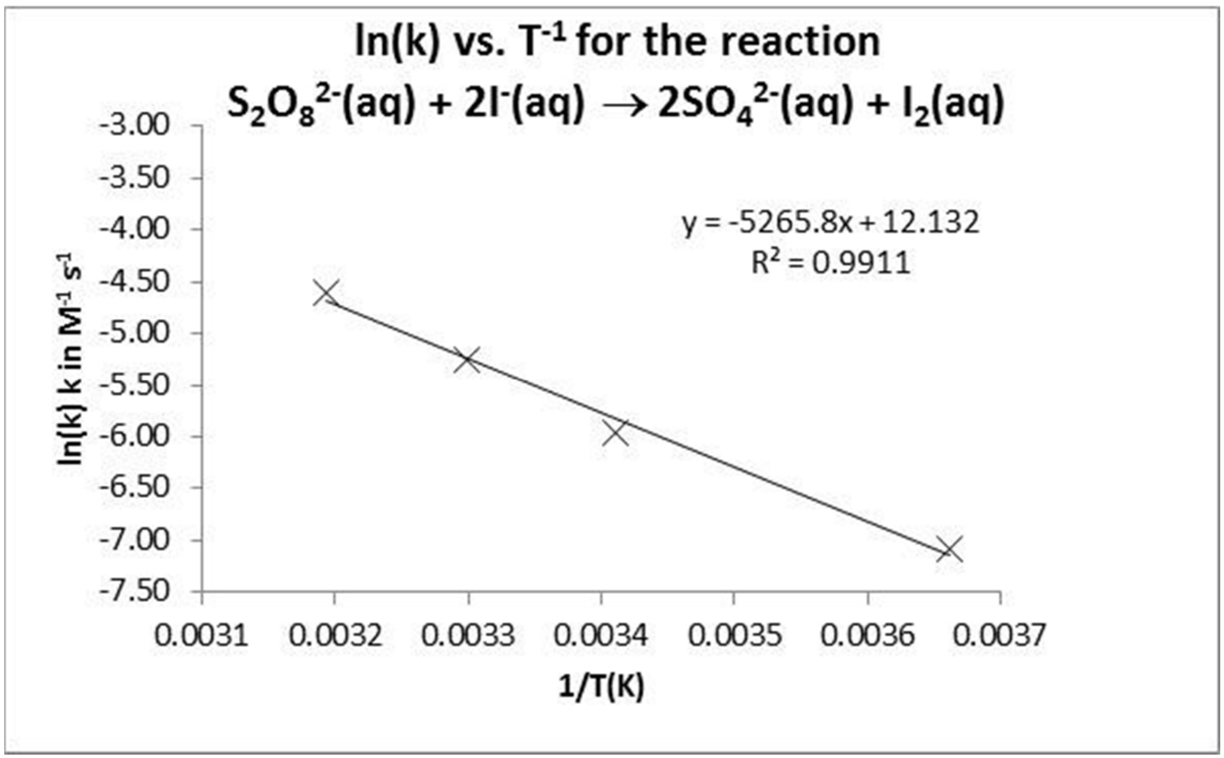
$$\text{Plot "}\ln k \text{ versus } \frac{1}{T}\text{"}$$ should yield a straight line!!

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part B - To study the effect of temperature on the rate of a reaction.



$$m = -\frac{E_a}{R} \quad \Rightarrow \quad E_a = -Rm$$

$$b = \ln(A) \quad \Rightarrow \quad A = e^b$$

Reaction Kinetics

Hebden – Unit 1 (page 1-34)

Experiment 2: Factors Affecting Reaction Rates

Objective: Part C - To study the effect of a catalyst on the rate of a reaction.

Use the A4, B4 solutions and add copper as a catalyst.

A catalyst speeds up a reaction.

When Cu is added, by how many times does the reaction increase?

$$\frac{\text{Rate of formation of } \mathrm{I_2} \text{ with Cu added}}{\textit{Rate of formation of } I_2 \textit{ without Cu}} > 1$$

Data from Part B.