Thiosulfate Reactions

A Level

Sodium thiosulfate is an immensely useful chemical. It is on the World Health Organisation's List of Essential Medicines, a list of the most important medications needed in a basic health system.

It is also used in hand warmers and, usefully for this question, kinetics experiments.

Part A Reaction equation

When sodium thiosulfate solution reacts with dilute hydrochloric acid, the solution becomes cloudy. The equation for this reaction is given below.

$$\mathrm{Na_2S_2O_3\,(aq) + 2\,HCl\,(aq) \longrightarrow 2\,NaCl\,(aq) + H_2O\,(l) + SO_2\,(g) + S\,(s)}$$

Which species causes the solution to become cloudy?

- $\mathrm{S\,(s)}$
- $\mathrm{H_2O\,(l)}$
- $\mathrm{SO_2\,(g)}$
- $\mathrm{NaCl\,(aq)}$

Part B Rate estimate

A chemist conducted an experiment to investigate how the concentration of $\mathrm{S_2O_3}^{2-}\,(\mathrm{aq})$ affects the time taken for the solution to become cloudy. Their results are as follows:

Concentration of sodium thiosulfate / $\mathrm{mol\,dm^{-3}}$	Time taken for the solution to become cloudy / seconds
0.040	69
0.060	44
0.080	35

Given that a good estimate of the rate of the reaction is given by:

$$\frac{1}{\text{time taken for solution to become cloudy}}$$

Calculate the rate when the concentration of sodium thiosulfate is $0.040\,\mathrm{mol\,dm^{-3}}$.

Part C Introduction to orders

The order of reaction with respect to a reactant indicates how much the rate changes with a change in the concentration of a reactant.

- In a zeroth order reaction, doubling the concentration of the reactant has no effect on the rate of the reaction.
- In a first order reaction, doubling the concentration of the reactant doubles the rate of reaction.
- In a second order reaction, doubling the concentration of the reactant quadruples the rate of reaction.
- And so on.

By calculating the rate of reaction when the concentration of $\mathrm{S_2O_3}^{2-}$ is $0.080\,\mathrm{mol\,dm^{-3}}$, and comparing this with the value when the concentration is $0.040\,\mathrm{mol\,dm^{-3}}$, calculate the order of the reaction with respect to sodium thiosulfate.

Part D Variability

Other than mistakes in measurement, which of the following options may have caused the non-exactness of the order you found in the previous question?

- The sulfur formed can begin to react with the dilute hydrochloric acid.
- The SO_2 formed is denser than air, so will sit in the flask and make the solution look more cloudy.
- Sulfur can dissolve in the water.
- Temperature variation during the experiment.

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Initial Rates

A Level

In an investigation to determine the order of reaction with respect to various reactants, the initial concentrations of the reactants were varied, and then the experiment was repeated. The reaction investigated was

$$\mathrm{A} + \mathrm{B} + \mathrm{C} \longrightarrow \mathrm{D}$$

A table of the results is given below.

Experiment number	Initial concentration of A/$\mathrm{mol\,dm^{-3}}$	Initial concentration of B/$\mathrm{mol\,dm^{-3}}$	Initial concentration of C/$\mathrm{mol\,dm^{-3}}$	Initial rate/ $\mathrm{mol\,dm^{-3}\,s^{-1}}$
1	0.900	1.80	0.100	3.24
2	1.20	0.900	0.100	0.810
3	0.600	1.80	0.200	6.48
4	0.300	0.200	0.300	?

Part A Order with respect to A

What is the order of reaction with respect to A?

Part B Order with respect to B

With respect to B?

Part C Order with respect to C

And with respect to C?

Part D Initial rate

Predict the initial rate of experiment 4.

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Concentration and Rate

A Level

The following data were obtained for the reaction between KOH and $\mathrm{CH_3COOCH_2CH_3}$ (its IUPAC name is ethyl ethanoate, but it is more commonly called ethyl acetate) in water at $50\,^{\circ}\mathrm{C}$.

Experiment number	**Initial concentration of** KOH**/**$\mathrm{mol\,dm^{-3}}$	**Initial concentration of ethyl acetate/**$\mathrm{mol\,dm^{-3}}$	**Initial rate/** $\mathrm{mol\,dm^{-3}\,min^{-1}}$
1	0.05	0.10	0.04
2	0.10	0.10	0.08
3	0.20	0.10	0.16
4	0.20	0.20	0.32
5	0.20	0.20	?

Part A Balanced equation

Write the simplest balanced equation for this reaction, using molecular formulae. State symbols are not required.

Part B Order of reaction

What is the order of reaction with respect to KOH?

What is the order of reaction with respect to ethyl acetate, $\mathrm{CH_3COOCH_2CH_3}$?

Hence, what is the overall order of this reaction?

Part C Rate equation

Write the rate equation for this reaction, using A to denote the concentration of KOH, B to denote the concentration of $\mathrm{CH_3COOCH_2CH_3}$, k to denote the rate constant, and r to denote the rate.

The following symbols may be useful: `A, B, k, r`

Part D Rate constant

Now, using the above equation, and the given data, calculate the rate constant.

Part E Determining the initial rate

Predict the initial rate of experiment 5.

Part F Effect of temperature

If the experiments were instead carried out at $30\,^{\circ}\mathrm{C}$, how would the rates change?

- The rates would increase.
- The rates would decrease.
- The rates of some of the experiments would increase, while the rates of the other experiments would decrease.
- The rates would stay the same.
- We need to know if this is an exothermic or endothermic reaction before predicting this.

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Graphing Concentration and Time

A Level

The decomposition of dinitrogen pentoxide according to the equation

$$\mathrm{N_2O_5} \longrightarrow 2\,\mathrm{NO_2} + \frac{1}{2}\,\mathrm{O_2}$$

was studied as follows.

Using a solution of dinitrogen pentoxide in tetrachloromethane the concentration of the oxide, $\mathrm{N_2O_5}$, remaining at various times during the decomposition was measured at a temperature of $318\,\mathrm{K}$. We use the notation $b = [\mathrm{N_2O_5}]$.

t / min	b / mol dm^{-3}
0	3.0
10	2.0
20	1.4
30	0.95
40	0.63
50	0.42
60	0.29
70	0.19

Part A Concentration time graph

Plot a graph of the concentration of $\mathrm{N_2O_5}$ against time, and from this determine the time taken for the concentration to fall to half its original value.

And to fall to a quarter of its original value?

And to an eighth?

Part B Order of reaction

From these values, what is the order of this reaction?

Part C Rate equation

Now you know the order of reaction, what is the rate equation for this reaction? Use r to denote the rate, k to denote the rate constant, and b to denote the concentration of $\mathrm{N_2O_5}$.

The following symbols may be useful: `b, k, r`

Part D Rate constant

What is the value of the rate constant, k, at this temperature?

Part E Effect of temperature

If the reaction was carried out at a constant temperature greater than $318\,\mathrm{K}$, how would the rate constant change?

- It would increase.
- It depends on whether this is an exothermic or endothermic reaction.
- It would stay the same.
- It would decrease.

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Rate Equations and Mechanisms

A Level

The two steps in the gas phase reaction $\mathrm{X} + 2\,\mathrm{Y} \longrightarrow \mathrm{XY_2}$ are given below:

$$\mathrm{X} + \mathrm{Y} \xrightarrow{\text{slow}} \mathrm{XY}$$

$$\mathrm{XY} + \mathrm{Y} \xrightarrow{\text{fast}} \mathrm{XY_2}$$

What is the rate equation for the overall reaction?

- rate = $k[XY]^1[Y]^1$
- rate = $k[X]^0[Y]^2$
- rate = $k[X]^0[Y]^1$
- rate = $k[X]^1[Y]^2$

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Essential Pre-Uni Chemistry M1.1

A Level

Equation 1: $\mathrm{A} \longrightarrow \mathrm{B}$

Equation 2: $\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C}$

Equation 3: $\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C} + \mathrm{D}$

Equation 4: $2\,\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C} + \mathrm{D}$

Rate law 1: rate = k

Rate law 2: rate $= k[\mathrm{A}]$

Rate law 3: rate $= k[\mathrm{A}]^2$

Rate law 4: rate $= k[\mathrm{A}][\mathrm{B}]$

Rate law 5: rate $= k[\mathrm{A}][\mathrm{B}]^2$

Rate law 6: rate $= k[\mathrm{A}][\mathrm{B}][\mathrm{cat}]$

Part A Equation 1: order of reaction

A reaction described by equation 1 gets three times faster when the concentration of A is tripled. Give the order of reaction with respect to A.

Give the overall order of the reaction.

Part B Equation 2: rate law

If equation 2 proceeds as a single step, which rate law will it follow?

Part C Second order rate laws

Which rate law(s) is/are second order overall?

- 3 and 4
- 4 and 6
- 3 and 5
- 1 and 2

Part D Units of k

In which rate law(s) is/are the units of the rate constant, k, $\mathrm{mol\,dm^{-3}\,s^{-1}}$? If your answer includes more than one rate law, please list them as one number in ascending order: to answer rates laws 2, 4 and 6, type 246.

Part E Law 6: power of dm

In rate law 6, the rate constant, k, has units which include dm raised to which power?

Part F Law 5: reaction order of B

What is the order of reaction with respect to B in rate law 5?

Part G Constant half-life

Which rate law(s) describe a reaction in which reactant A always has constant half-life? If your answer includes more than one rate law, please list them as one number in ascending order: to answer rates laws 2, 4 and 6, type 246.

Part H Law 2: rate constant

In rate law 2, if $[\mathrm{A}] = 0.020\,\mathrm{mol\,dm^{-3}}$, and the $\mathrm{rate\ of\ reaction} = 1.2 \times 10^{-3}\,\mathrm{mol\,dm^{-3}\,s^{-1}}$, find the value of k.

Part I Law 2: rate of reaction

In rate law 2, if k has a value of $150\,\mathrm{s^{-1}}$, find the rate of reaction when $[\mathrm{A}] = 0.80\,\mathrm{mol\,dm^{-3}}$.

Part J Law 3: $[\mathrm{A}]$

In rate law 3, find $[\mathrm{A}]$ at which the $\mathrm{reaction\ rate} = 0.025\,\mathrm{mol\,dm^{-3}\,s^{-1}}$ if $k = 0.0040\,\mathrm{dm^3\,mol^{-1}\,s^{-1}}$.

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Essential Pre-Uni Chemistry M1.5

A Level

Use the data in the table below to find the order of reaction with respect to A, B and the catalyst, X, the overall order of reaction, and the value and units of the rate constant, k.

$[\mathrm{A}]\ /\ \mathrm{mol\,dm^{-3}}$	$[\mathrm{B}]\ /\ \mathrm{mol\,dm^{-3}}$	$[\mathrm{X}]\ /\ \mathrm{mol\,dm^{-3}}$	$\mathrm{Rate}\ /\ \mathrm{mol\,dm^{-3}\,s^{-1}}$
0.50	0.080	0.0020	3.2×10^{-3}
0.50	0.080	0.0010	8.0×10^{-4}
0.75	0.080	0.0010	1.2×10^{-3}
0.75	0.040	0.0010	6.0×10^{-4}

Part A Order with respect to A

Order with respect to A:

Part B Order with respect to B

Order with respect to B:

Part C Order with respect to X

Order with respect to X:

Part D Overall order

Overall order:

Part E k

Value of k:

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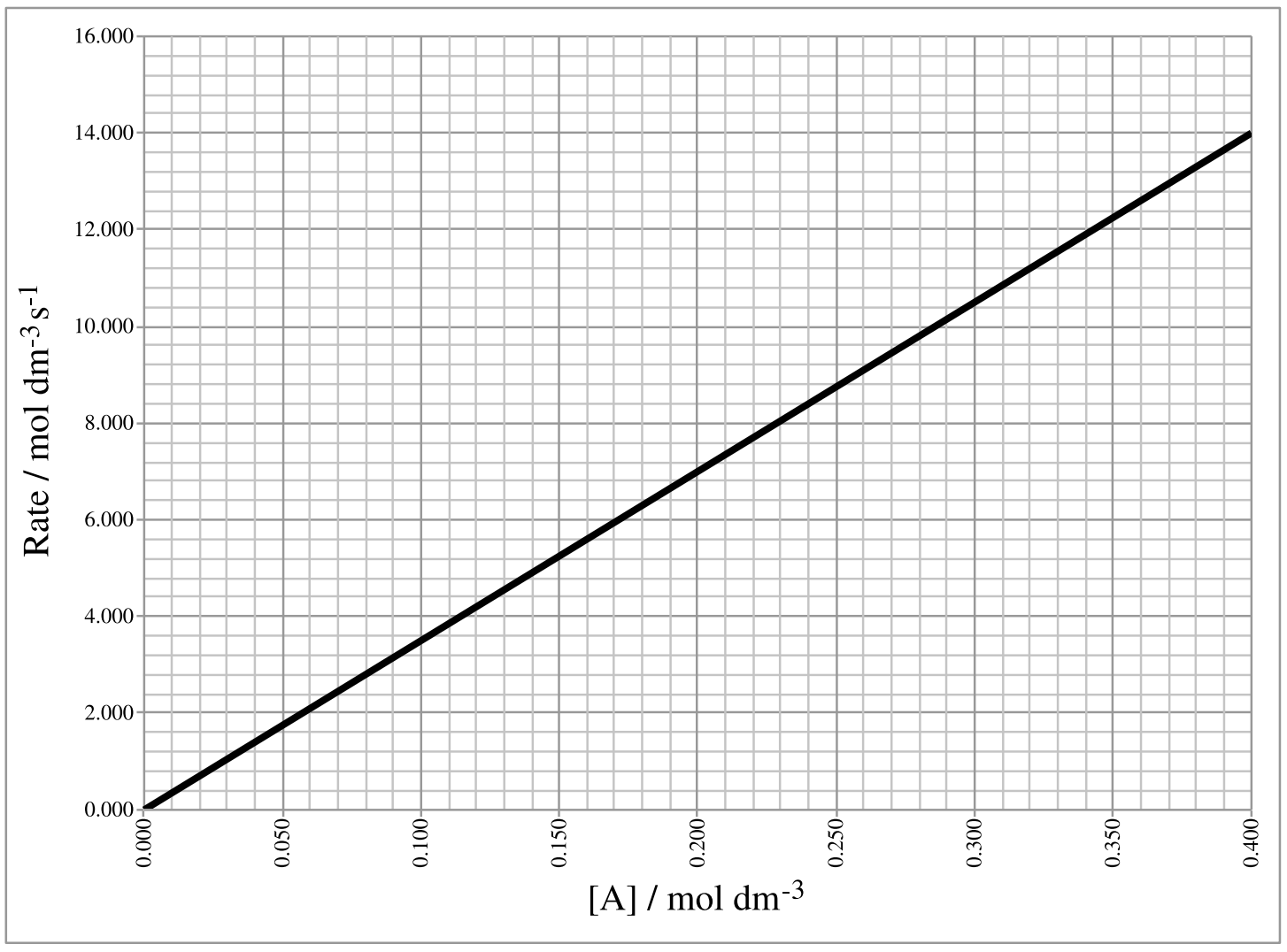
Essential Pre-Uni Chemistry M1.10

A Level

Equation 2: $\mathrm{A} + \mathrm{B} \longrightarrow \mathrm{C}$

Rate law 4: rate $= k[\mathrm{A}][\mathrm{B}]$

A reaction described by equation 2 and obeying rate law 4 gave the following initial rates for different initial concentrations of A without varying the initial concentration of B:



Estimate the initial concentration of B if the rate constant is $140\ \mathrm{dm^3\ mol^{-1}\ s^{-1}}$. Give your answer to 2 significant figures.

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Iodine Oxidation States

A Level

Iodate and iodide ions react in aqueous solution as follows:

$$a\,\mathrm{IO_3}^-\,(\mathrm{aq}) + b\,\mathrm{I}^-\,(\mathrm{aq}) + c\,\mathrm{H}^+\,(\mathrm{aq}) \longrightarrow d\,\mathrm{I_2}\,(\mathrm{aq}) + e\,\mathrm{H_2O}\,(\mathrm{l})$$

The initial rates of the formation of iodine were found for different concentrations of iodate ions and iodide ions at $\mathrm{pH} = 7$ and $298\,\mathrm{K}$.

$[\mathrm{IO_3}^-]\ /\mathrm{mol\,dm^{-3}}$	$[\mathrm{I}^-]\ /\mathrm{mol\,dm^{-3}}$	**Initial rate,** $\left(\frac{\mathrm{d}[\mathrm{I_2}]}{\mathrm{d}t}\right)\ /\mathrm{mol\,dm^{-3}\,s^{-1}}$
0.030	0.30	4.4×10^{-5}
0.030	0.60	7.0×10^{-4}
0.060	0.30	1.8×10^{-4}
0.060	0.60	2.8×10^{-3}

Part A Coefficients

What are the coefficients of the reaction? Enter your answer in the form $abcde$ with no spaces.

Part B Order of reaction

Use the data above to find the values of a and b in the rate equation:

$$\frac{\mathrm{d}[\mathrm{I_2}]}{\mathrm{d}t} = k[\mathrm{IO_3}^-]^a\,[\mathrm{I}^-]^b$$

Write your answer in the form ab with no space.

Part C Time estimate

$10\,\mathrm{cm}^3$ of a solution containing $2.4 \times 10^{-3}\,\mathrm{mol}$ of potassium iodate is added to $10\,\mathrm{cm}^3$ of solution containing $3.0 \times 10^{-3}\,\mathrm{mol}$ of potassium iodide, $2.0 \times 10^{-5}\,\mathrm{mol}$ sodium thiosulfate and a little starch.

Estimate how long it takes for the solution to turn blue (give your answer to 2 s.f.).

Part D Iodine question

In the presence of concentrated hydrochloric acid, iodate and iodide ions react in a different way. $20\,\mathrm{cm}^3$ of $0.050\,\mathrm{mol\,dm}^{-3}$ potassium iodide was mixed with $30\,\mathrm{cm}^3$ of $1\,\mathrm{M}$ concentrated hydrochloric acid. $0.050\,\mathrm{mol\,dm}^{-3}$ potassium iodate solution was added and initially the solution turned brown due to the formation of iodine. After $10\,\mathrm{cm}^3$ had been added, the solution turned colourless.

What is the iodine containing product of the reaction?

Determine the concentration of HCl which remains in the solution.

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Temperature Variation

A Level

C C C

Two substances, X and Y, react in an inert solvent according to the following equation:

$$\mathrm{X} + 2\,\mathrm{Y} \longrightarrow \mathrm{XY_2}.$$

The following experiments were run to determine the order of the reaction between X and Y, at $20\,^\circ\mathrm{C}$.

Experiment number	Initial concentration of $\mathrm{X}/\mathrm{mol\,dm^{-3}}$	Initial concentration of $\mathrm{Y}/\mathrm{mol\,dm^{-3}}$	Initial rate of formation of $\mathrm{XY_2}/\mathrm{mol\,dm^{-3}\,min^{-1}}$
1	0.10	0.10	0.0010
2	0.10	0.20	0.0040
3	0.10	0.30	0.0090
4	0.15	0.10	0.0010
5	0.20	0.20	?

Part A Order of the reaction

What is the order of the reaction with respect to X and Y, respectively?

- 0; 2
- 1; 0
- 1; 2
- -1; -1
- 0; 1
- 2; 1

Part B Rate constant

Calculate the numerical value for the rate constant k.

Part C Initial rate of experiment 5

Predict the rate of formation of $\mathrm{XY_2}$ in experiment 5.

Part D Greatest reaction rate

The rate constant has an Arrhenius dependence on temperature. Knowing that the activation energy for the reaction is $53\,\mathrm{kJ\,mol^{-1}}$, which of the following sets of conditions will give the greatest rate of reaction?

- $[X] = 0.1\,\mathrm{mol\,dm^{-3}}$, $[Y] = 0.3\,\mathrm{mol\,dm^{-3}}$, $T = 30\,^\circ\mathrm{C}$.
- $[X] = 0.3\,\mathrm{mol\,dm^{-3}}$, $[Y] = 0.1\,\mathrm{mol\,dm^{-3}}$, $T = 20\,^\circ\mathrm{C}$.
- $[X] = 0.1\,\mathrm{mol\,dm^{-3}}$, $[Y] = 0.2\,\mathrm{mol\,dm^{-3}}$, $T = 40\,^\circ\mathrm{C}$.
- $[X] = 0.3\,\mathrm{mol\,dm^{-3}}$, $[Y] = 0.1\,\mathrm{mol\,dm^{-3}}$, $T = 30\,^\circ\mathrm{C}$.
- $[X] = 0.2\,\mathrm{mol\,dm^{-3}}$, $[Y] = 0.2\,\mathrm{mol\,dm^{-3}}$, $T = 30\,^\circ\mathrm{C}$.

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