A-Level Chemistry

Effect of Temperature, Concentration and Pressure

Question Paper

Time available: 54 minutes
Marks available: 50 marks

1. A student investigates the effect of temperature on the rate of reaction between sodium thiosulfate solution and dilute hydrochloric acid.

$$Na_2S_2O_3(aq) + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + SO_2(g) + S(s) + H_2O(l)$$

The student mixes the solutions together in a flask and places the flask on a piece of paper marked with a cross.

The student records the time for the cross to disappear. The cross disappears because the mixture becomes cloudy.

The table shows the student's results.

Temperature / °C	22	31	36	42	49	54
Time, t, for cross to disappear / s	87	48	36	26	44	12
$\frac{1}{t}$ / s^{-1}	0.0115	0.0208	0.0278	0.0385	0.0227	

(a) The student uses a stopwatch to measure the time. The stopwatch shows each time to the nearest 0.01 s

Suggest why the student records the times to the nearest second and not to the nearest 0.01 s

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(1)

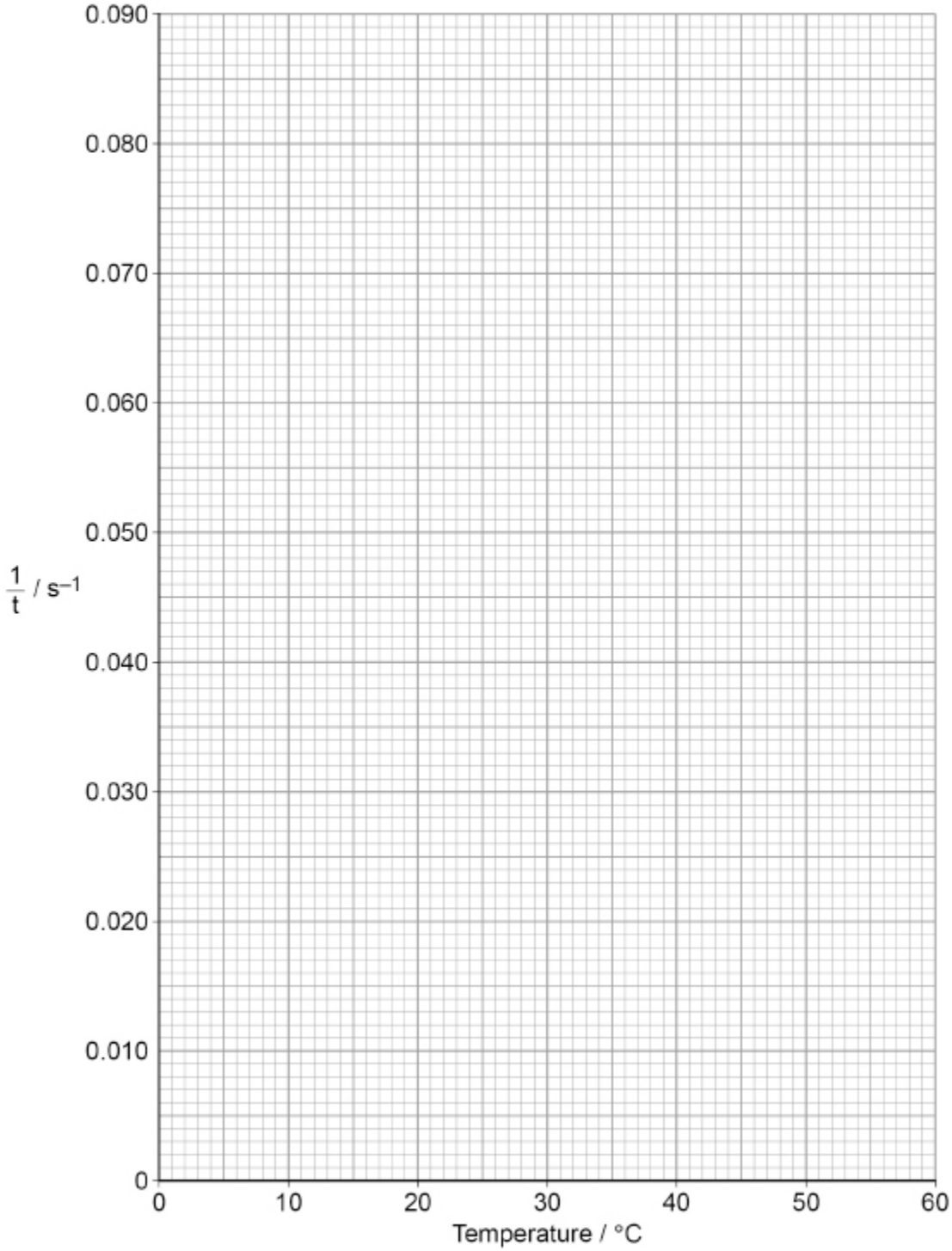
(b) The rate of reaction is proportional to $\frac{1}{t}$

Complete the table above.

(1)

(c) Plot the values of $\frac{1}{t}$ against temperature on the graph below.

Draw a line of best fit.



(2)

(d) Use your line of best fit to estimate the time for the cross to disappear at 40 °C
Show your working.

Time _____ s

(1)

(e) Suggest, by considering the products of this reaction, why small amounts of reactants are used in this experiment.

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(1)

(f) The student could do the experiment at lower temperatures using an ice bath.

Suggest why the student chose **not** to carry out experiments at temperatures in the range 1–10 °C

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(1)

(Total 7 marks)

2. Methanol (CH_3OH) is an important alcohol with many uses.

(a) Draw a diagram to show how two methanol molecules interact with each other through hydrogen bonding in the liquid phase.

Include all partial charges and all lone pairs of electrons in your diagram.

(3)

(b) The bond angle around the oxygen atom in methanol is slightly smaller than the regular tetrahedral angle of 109.5°

Explain why this bond angle is smaller than 109.5°

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(1)

(c) Methanol is made by the reaction of carbon monoxide with hydrogen.

$$CO + 2\ H_2 \rightleftharpoons CH_3OH \qquad \Delta H = -91\ kJ\ mol^{-1}$$

The reaction uses a copper-based catalyst, a pressure of 10 MPa and a temperature of 550 K

These conditions are used to provide a balance between equilibrium yield, reaction rate and cost.

Describe how the use of a catalyst, and changes in pressure and temperature, each affect equilibrium yield, reaction rate and cost.

(6)

(Total 10 marks)

3. This question is about rates of reaction.

Potassium manganate(VII), $KMnO_4$, reacts with sodium ethanedioate, $Na_2C_2O_4$, in the presence of dilute sulfuric acid.

$$2\ MnO_4^-(aq) + 16\ H^+(aq) + 5\ C_2O_4^{2-}(aq) \rightarrow 2\ Mn^{2+}(aq) + 8\ H_2O(l) + 10\ CO_2(g)$$

The reaction mixture is purple at the start and goes colourless when all the $MnO_4^-(aq)$ ions have reacted.

The rate of reaction can be measured as $\frac{1000}{t}$ where t = the time taken for the mixture to go colourless.

A student investigated how long it takes for this reaction mixture to go colourless at different temperatures. The same concentrations and volumes of each reagent were used in an experiment at each temperature. The table below shows the results.

Temperature / °C	32	38	44	54	67
Time *t* / s	155	85	50	22	9
$\frac{1000}{t}$	6.45	11.8	20.0	45.5	

(a) Complete the table above.

(1)

(b) State the independent variable in this investigation.

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(1)

(c) The student noticed that the temperature of each reaction mixture decreased during each experiment.

Suggest how the student calculated the temperature values in the table above.

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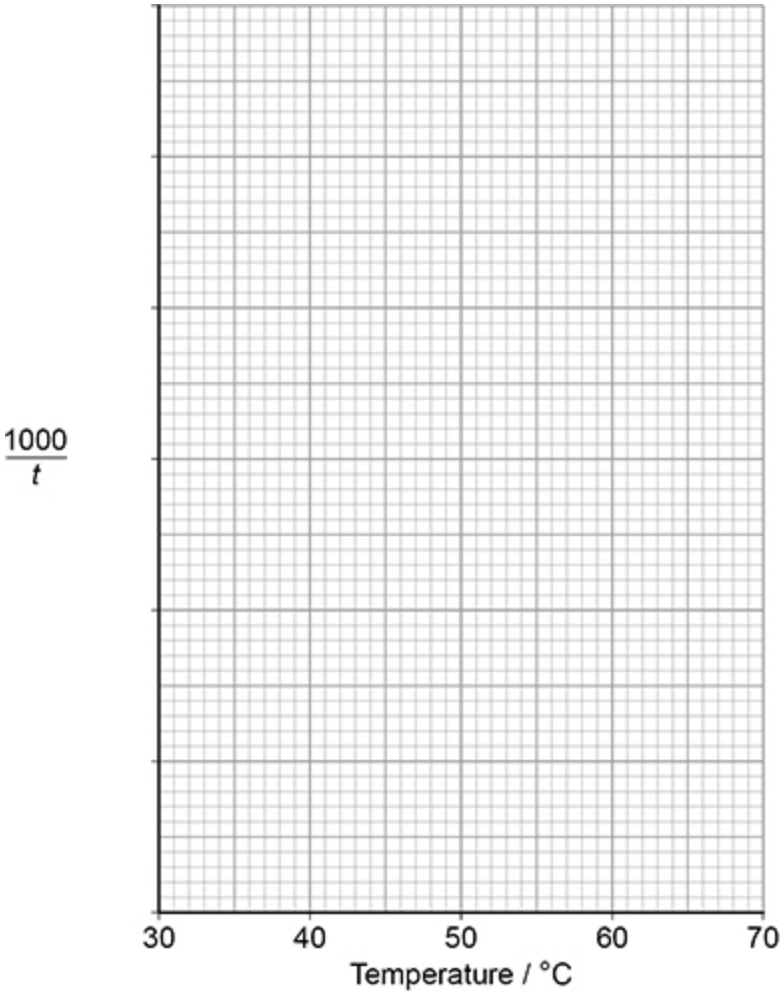
(1)

(d) Use the data in the table to plot a graph of $\frac{1000}{t}$ against temperature.



(3)

(e) Use your graph in part (d) to find the time taken for the mixture to go colourless at 60 °C
Show your working.

Time *t* _____ s

(1)

(f) The investigation shows that increasing the temperature causes the rate of reaction to increase.

Explain why a small increase in temperature causes a large increase in the rate of reaction.

(2)

(Total 9 marks)

4. The gas-phase reaction between hydrogen and chlorine is very slow at room temperature.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

(a) Define the term *activation energy*.

(2)

(b) Give **one** reason why the reaction between hydrogen and chlorine is very slow at room temperature.

(1)

(c) Explain why an increase in pressure, at constant temperature, increases the rate of reaction between hydrogen and chlorine.

(2)

(d) Explain why a small increase in temperature can lead to a large increase in the rate of reaction between hydrogen and chlorine.

(2)

(e) Give the meaning of the term *catalyst*.

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(1)

(f) Suggest **one** reason why a solid catalyst for a gas-phase reaction is often in the form of a powder.

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(1)

(Total 9 marks)

5. Hydrogen is produced in industry from methane and steam in a two-stage process.

(a) In the first stage, carbon monoxide and hydrogen are formed.
The equation for this reaction is

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206 \text{ kJ mol}^{-1}$

(i) Use Le Chatelier's principle to state whether a high or low temperature should be used to obtain the highest possible equilibrium yield of hydrogen from this first stage. Explain your answer.

Temperature _____

Explanation _____

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(3)

(ii) Le Chatelier's principle suggests that a high pressure will produce a low yield of hydrogen in this first stage.

Explain, in terms of the behaviour of particles, why a high operating pressure is used in industry.

(2)

(iii) A nickel catalyst is used in the first stage.

Explain why the catalyst is more effective when coated onto an unreactive honeycomb.

(2)

(b) The second stage is carried out in a separate reactor. Carbon monoxide is converted into carbon dioxide and more hydrogen is formed.

The equation for this reaction is

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -41$ kJ mol^{-1}

Use Le Chatelier's principle to state the effect, if any, of a **decrease** in the total pressure on the yield of hydrogen in this second stage. Explain your answer.

Effect _____

Explanation _____

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(2)

(Total 9 marks)

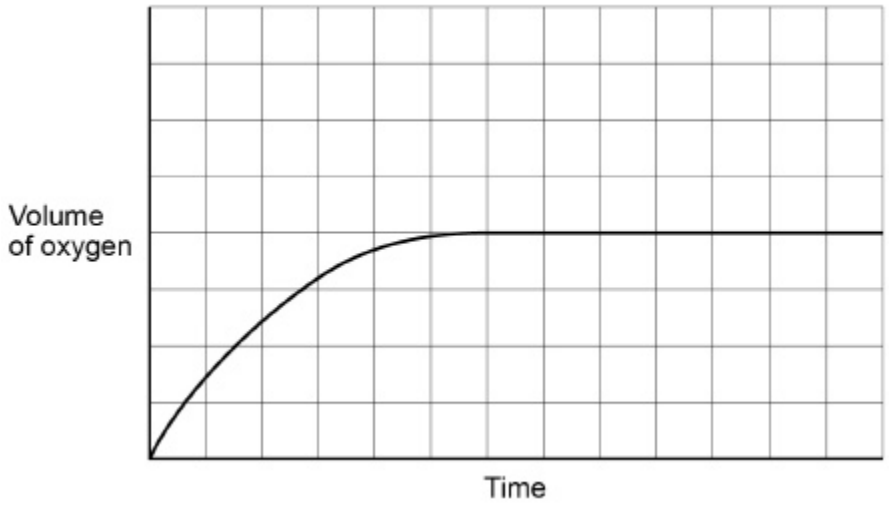
6. Hydrogen peroxide solution decomposes slowly to form water and oxygen.
The reaction is much faster in the presence of a manganese(IV) oxide catalyst.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

Three experiments, shown in the table, were carried out to investigate how the volume of oxygen produced varied over time under different conditions. The same mass of catalyst was used in each experiment.

Experiment	Concentration of H_2O_2(aq) / mol dm^{-3}	Volume of H_2O_2(aq) / cm^3	Temperature / °C	Catalyst
1	1.0	50	20	lumps
2	1.0	50	20	powder
3	0.5	50	20	lumps

The graph shows how the volume of oxygen collected varied with time in Experiment **1**.



(a) Explain, in general terms, how a catalyst increases the rate of a reaction.

(2)

(b) Draw **two** lines on the graph to show how the volume of oxygen collected varied with time in Experiments **2** and **3**.
Label each line with the experiment number.

(2)

(c) Explain, in terms of collision theory, the effect of increasing the concentration of hydrogen peroxide on the rate of reaction.

(2)

(Total 6 marks)