Answer **all** the questions in the spaces provided.

1 Determination of a value for an enthalpy change of decomposition, ΔH^1_{decomp}

Hydrogen peroxide decomposes very slowly to form water and oxygen gas as shown in equation **1**. The enthalpy change of decomposition, ΔH_{decomp}, for this reaction is exothermic.

equation **1** $2H_2O_2 \rightarrow 2H_2O + O_2$ ΔH_{decomp}

Many transition element ions are able to catalyse the decomposition of hydrogen peroxide. Iron(III) nitrate, $Fe(NO_3)_3$, is an effective catalyst for this reaction.

FA 1 is 0.850 mol dm^{-3} aqueous hydrogen peroxide, H_2O_2.
FA 2 is iron(III) nitrate, $Fe(NO_3)_3$.

The addition of **FA 2** to **FA 1** increases the rate of decomposition of H_2O_2. This increase is sufficient to allow the maximum temperature change, ΔT_{max}, to be determined within a few minutes.

In this question, you will perform an experiment to determine a value for ΔT_{max}. You will then repeat this experiment and hence determine the average maximum temperature change, ΔT^1_{max}.

You will use your value of ΔT^1_{max} to calculate a value for the enthalpy change for the decomposition reaction shown in equation **1**, ΔH^1_{decomp}.

In **1(d)**, you will use data provided to determine another value for the maximum temperature change, ΔT^2_{max}. You will then calculate a second value for the enthalpy change for the decomposition reaction shown in equation **1**, ΔH^2_{decomp}.

(a) Perform the tests described in Table 1.1, and record your observations in the table. Test and identify any gases evolved.

Table 1.1

	tests	observations
1.	Test the **FA 2** solution using Universal Indicator paper.	Universal Indicator paper turns red / orange, indicating pH = 3 (match with chart provided)
2.	Put about a 2 cm depth of **FA 1** into a test-tube. Add about a 2 cm depth of **FA 2** to the same test-tube and shake the mixture thoroughly. Observe the mixture until no further changes are seen.	 When yellow **FA 2** is added to colourless **FA 1**, the solution turns brown. Vigorous effervescence of colourless, odourless gas. Gas relights a glowing splint. Gas is oxygen. After a few minutes, the reaction mixture turns yellow.
While you are waiting, continue with (b).		

[2]

(b) Determination of the average maximum temperature change, ΔT^1_{max}, for the catalysed decomposition of hydrogen peroxide, FA 1

You will follow the instructions to perform the experiment twice, run A and run B.

Record your results in Table 1.2.

(i)
1. Using a measuring cylinder, transfer 50.0 cm^3 of **FA 1** into a Styrofoam cup. Place this cup inside a second Styrofoam cup, which is placed in a 250 cm^3 glass beaker.
2. Stir and measure the temperature of this **FA 1**, $T_{FA\,1}$.
3. Using another measuring cylinder, measure 50.0 cm^3 of **FA 2**.
4. Stir and measure the temperature of this **FA 2**, $T_{FA\,2}$.
5. Add the **FA 2** from the measuring cylinder to the **FA 1** in the Styrofoam cup.
6. Using the thermometer, stir the mixture continuously until it reaches its maximum temperature. This could take several minutes. Record this temperature, T_{max}.
7. Replace the wet Styrofoam cup with a clean, dry Styrofoam cup. Repeat steps **1** to **6** to obtain a second value for T_{max}.

Complete Table 1.2 by calculating values for the average of $T_{FA\,1}$ and $T_{FA\,2}$, T_{ave}, and ΔT_{max} for each run.

Table 1.2

	run A	run B
$T_{FA\,1}$ / °C	30.4	30.4
$T_{FA\,2}$ / °C	30.5	30.4
T_{ave} / °C	30.5	30.4
T_{max} / °C	38.9	38.8
ΔT_{max} / °C	+8.4	+8.4

Determine the average maximum temperature change, ΔT^1_{max}.

Average ΔT^1_{max} = (8.4 + 8.4) / 2 = +8.4 °C

ΔT^1_{max} = +8.4 °C ..... °C [2]

Note: must include + or – sign for "change"

(ii) Calculate the average heat change, q, for your experiment in **1(b)(i)** and hence determine a value for the enthalpy change, for the decomposition reaction shown in equation **1**, ΔH^1_{decomp}.

You should assume that the:

- decomposition of H_2O_2 in **FA 1** is complete when T_{max} is reached;
- specific heat capacity of the mixture is $4.18\,J\,g^{-1}\,K^{-1}$;
- density of the mixture is $1.00\,g\,cm^{-3}$.

Average heat change, q = m_{aq} c ΔT
= 100 × 4.18 × 8.4
= 3511.2
= 3510 J

q = 3510 J

No of mol of H_2O_2 = $\frac{50}{1000}$ × 0.85 = 0.0425 mol

$\Delta H_{rxn} = \frac{-3511.2}{0.0425}$ = −82.62 kJ mol^{-1} (per mol of H_2O_2)

ΔH^1_{decomp} = −82.62 × 2 = −165 kJ mol^{-1} (for 2 mol of H_2O_2 as shown in eqn 1)

ΔH^1_{decomp} = −165 kJ mol^{-1}

Note: must include – sign as reaction is exothermic (ΔT is +ve) [3]

(c) Steps **1** to **4** represent a possible mechanism for the catalysed decomposition of H_2O_2. In this mechanism, the O_2H ligand on one of the complex ions represents the H–O–O$^-$ ion and the O represents an oxygen atom.

step **1** $[Fe(H_2O)_6]^{3+}(aq) + H_2O_2(aq) \rightleftharpoons [Fe(H_2O)_5(O_2H)]^{2+}(aq) + H_3O^+(aq)$

step **2** $[Fe(H_2O)_5(O_2H)]^{2+}(aq) \rightarrow OH^-(aq) + [Fe(H_2O)_5O]^{3+}(aq)$

step **3** $[Fe(H_2O)_5O]^{3+}(aq) + H_2O_2(aq) \rightarrow [Fe(H_2O)_6]^{3+}(aq) + O_2(g)$

step **4** $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$

(i) Explain fully how you can tell that the $[Fe(H_2O)_6]^{3+}$ ions are acting as a catalyst in this reaction, using evidence from your observations in Table 1.1 and from the mechanism.

$[Fe(H_2O)_6]^{3+}$ does not appear in the overall equation of the decomposition of H_2O_2. it is consumed in step 1 and regenerated in step 3 of the mechanism, this shows that it acts as a catalyst in the reaction.
The starting species $[Fe(H_2O)_6]^{3+}$ is yellow. During the reaction, the mixture turned brown, however, the yellow colour is obtained again at the end of the reaction.
Before $[Fe(H_2O)_6]^{3+}$ was added, there was no effervescence seen in H_2O_2. However upon adding $[Fe(H_2O)_6]^{3+}$, vigorous effervescence is observed, implying that $[Fe(H_2O)_6]^{3+}$ acts as a catalyst and speed up the decomposition of H_2O_2.

[3]

(ii) The crystals of hydrated iron(III) nitrate, $Fe(NO_3)_3.9H_2O$, used to prepare your sample of **FA 2** were pale violet in colour.

The colour of the **FA 2** solution obtained by dissolving these crystals is due to the $[Fe(H_2O)_6]^{3+}$ ion reacting with a water molecule.

Complete the equation and explain how you deduced the products of this reaction, using your observations from test 1 in Table 1.1 to help you.

$[Fe(H_2O)_6]^{3+} + H_2O \longrightarrow [Fe(H_2O)_5(OH)]^{2+} + H_3O^+$

explanation From test 1, colour of Universal Indicator paper is orange-red which shows that the solution is acidic (pH = 3). Fe^{3+} has high charge over size ratio, polarises and weakens the O−H bond of H_2O, causing one of the six H_2O to undergo hydrolysis to give $[Fe(H_2O)_5(OH)]^{2+}$ and H_3O^+, resulting in an acidic solution.

[2]

(iii) Explain the colour changes you observed for test 2 in Table 1.1, in terms of the complex ions involved in the mechanism.

$[Fe(H_2O)_5(OH)]^{2+}$ is yellow solution while $[Fe(H_2O)_5O]^{3+}$ is brown solution.
After $[Fe(H_2O)_6]^{3+}$ is regenerated in step 3 of the mechanism, it reacts with H_2O and undergoes hydrolysis to give $[Fe(H_2O)_5(OH)]^{2+}$

.....[1]

(d) Determination of a value for an enthalpy change of decomposition, ΔH^2_{decomp}, using a graphical method

A student performed the experiment you performed in **1(b)(i)** but measured the temperature at timed intervals. The student added **FA 2**, containing the $[Fe(H_2O)_6]^{3+}$ catalyst, to the **FA 1** at four minutes.

The results from this experiment are plotted on the grid in Fig. 1.1.

(i) Draw two best-fit straight lines, the first taking into account the points before the **FA 2** was added and the second taking into account the points after the reaction had finished.

Extrapolate (extend) both lines to four minutes.

Determine a value for the maximum temperature change, ΔT^2_{max}, at t = 4.0 min using the graph.

At t = 4 min, T_{max} = 33.0°C
At t = 4 min, $T_{initial}$ = 21.5°C
ΔT^2_{max} = 33.0 – 21.5 = +11.5°C

ΔT^2_{max} = ... +11.5 .....°C [2]

(ii) Calculate a second value for the enthalpy change for the decomposition reaction shown in equation **1**, ΔH^2_{decomp}, using this value of ΔT^2_{max}.

heat change, $q = m_{aq}c\Delta T = 100 \times 4.18 \times 11.5$
$= 4807$ J

$\Delta H^2_{decomp} = \frac{-4807}{0.0425} \times 2 = -226211$ J mol^{-1}
$= -226$ kJ mol^{-1} (for 2 mol of H_2O_2 as shown in eqn 1)

ΔH^2_{decomp} = ... −226 kJ mol^{-1} ..... [1]

(iii) State which of the temperature changes, ΔT^1_{max} or ΔT^2_{max}, is likely to be more accurate. Explain why your chosen value is likely to be the more accurate one.

ΔT^2_{max} is likely to be more accurate as the heat lost to the environment is accounted for through the extrapolation temperature readings to the time of mixing (t = 4 min).

.....[1]

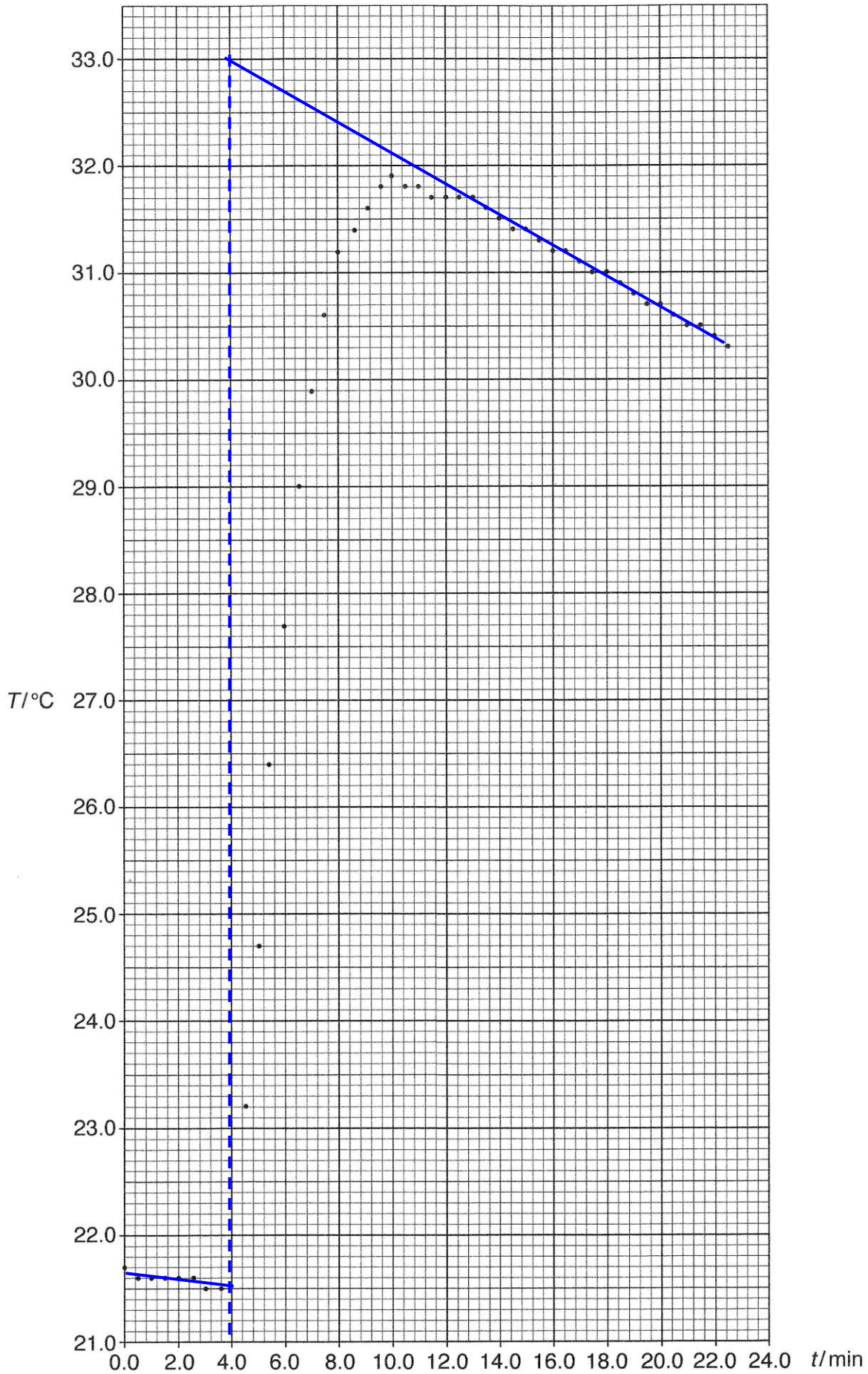

Fig. 1.1

[Total: 17]

2 Investigation of the kinetics of the catalysed decomposition of hydrogen peroxide

The concentration of **FA 1** is too high for the **FA 1** to be titrated directly against **FA 3**. A diluted solution of **FA 1** has been provided for you. This diluted solution is **FA 4**.

FA 3 is 0.0200 mol dm^{-3} potassium manganate(VII), $KMnO_4$.
FA 4 is 0.170 mol dm^{-3} aqueous hydrogen peroxide, H_2O_2.

You are also provided with 0.2 mol dm^{-3} sulfuric acid, H_2SO_4.

You will add a measured volume of **FA 2** to a measured volume of **FA 4** and, at timed intervals, you will transfer aliquots (portions) of the reaction mixture.

It is necessary that you titrate each aliquot against **FA 3 before** transferring the next aliquot.

Acidified $KMnO_4$ and H_2O_2 react as shown in equation **2**.

equation **2** $2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \longrightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 5O_2(g)$

(a) (i) Preparation and titration of the reaction mixture

Notes: You will perform each titration **once** only. Great care must be taken that you do not overshoot the end-point.

Once you have started the stopwatch, it must continue running for the duration of the experiment. You must **not** stop it until you have finished this experiment.

You should aim to transfer your first aliquot within the first three minutes of starting the reaction.

You should aim **not** to exceed a maximum reaction time of 25 minutes for this experiment.

In an appropriate format in the space provided, prepare a table in which to record for each aliquot

- the time of transfer, t, in minutes and seconds,
- the decimal time, t_d, in minutes, to 0.1 min, for example, if t = 4 min 33 s then t_d = 4 min + 33/60 min = 4.6 min,
- the burette readings and the volume of **FA 3** added.

1. Fill a burette with **FA 3**.
2. Using a measuring cylinder, add 100.0 cm^3 of **FA 4** to the conical flask labelled **reaction mixture**.
3. Using a measuring cylinder, add 2.0 cm^3 of **FA 2** to the same conical flask. Start the stopwatch and swirl the mixture thoroughly to mix its contents.
4. Using a measuring cylinder, add 50.0 cm^3 of 0.2 mol dm^{-3} sulfuric acid to a second conical flask.
5. Transfer a 10.0 cm^3 aliquot (portion) of the reaction mixture to a 10 cm^3 measuring cylinder, using a dropping pipette.
6. **Immediately** transfer this aliquot into the second conical flask and vigorously swirl the mixture. Read and record the time of transfer in minutes and seconds, to the nearest second, when the aliquot is added.
7. **Immediately** titrate the H_2O_2 in the second conical flask with **FA 3**. The end-point is reached when a permanent **pale** pink colour is obtained. Record your titration results.
8. Wash out the second conical flask with water.
9. Repeat steps **4** to **8** until a total of **five** aliquots have been titrated and their results recorded.

Results

Time of transfer, t (time at which reaction mixture is quenched)	1 min 40 s	4 min 50 s	7 min 54 s	11 min 17 s	15 min 6 s
Decimal time, t_d /min	1.7	4.8	7.9	11.3	15.1
Final burette reading / cm^3	40.00	47.50	14.55	24.80	30.80
Initial burette reading / cm^3	12.40	27.75	0.75	14.60	24.80
Volume of **FA 3** added / cm^3	27.60	19.75	13.80	10.20	6.00

[4]

(ii) Plot a graph of the volume of **FA 3** added, on the *y*-axis, against decimal time, t_d, on the *x*-axis on the grid in Fig. 2.1.

Draw the most appropriate best-fit curve taking into account all of your plotted points. Extrapolate (extend) this curve to t_d = 0.0 min.

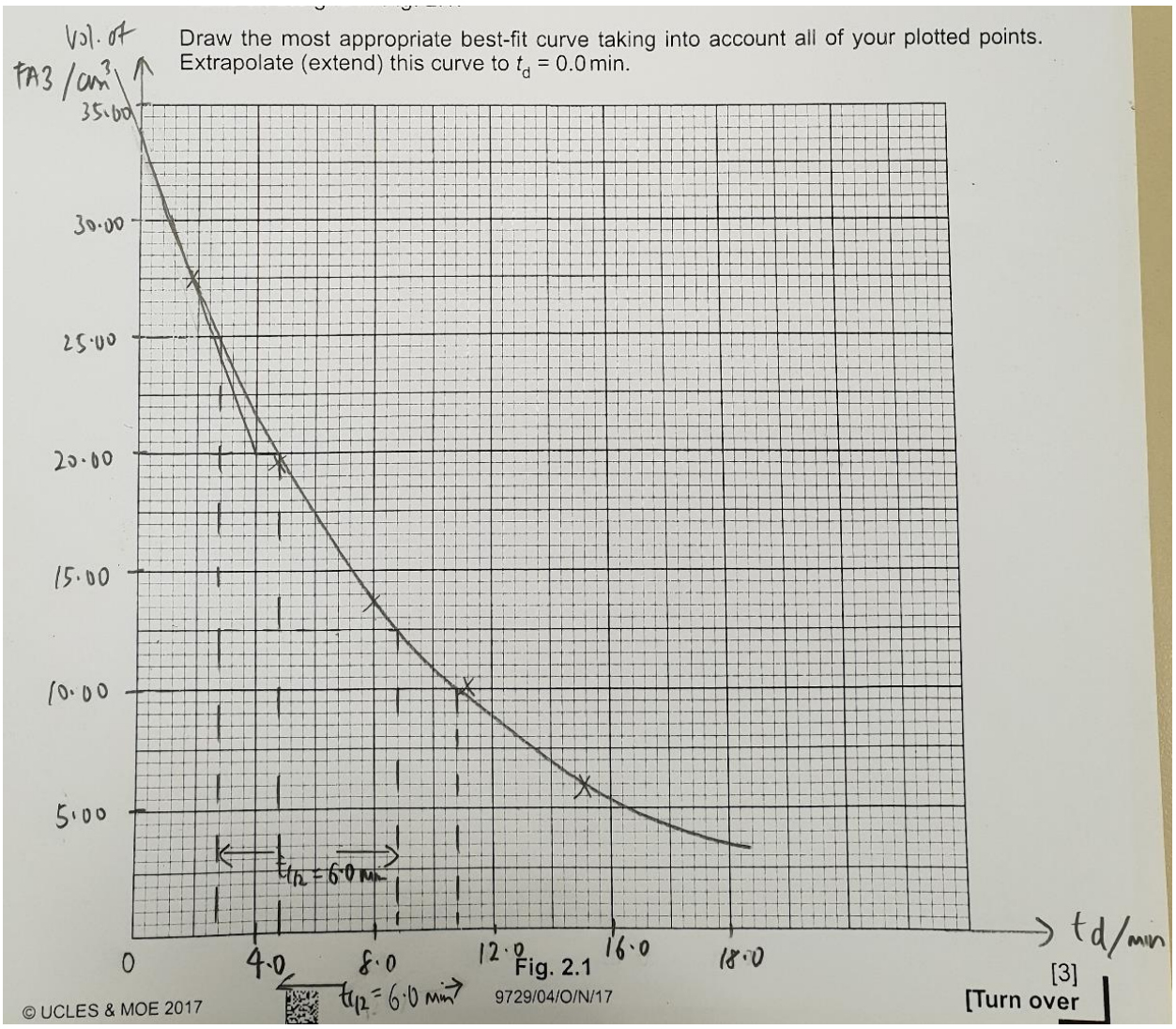

Fig. 2.1

[3]

Fig. 2.1

[3]

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[Turn over

(b) The **initial rate** of change of the concentration of hydrogen peroxide, **FA 4**, $[H_2O_2]$, can be determined from the gradient of the tangent to the graph in Fig. 2.1 at time t_d = 0.0 min.

(i) Draw a tangent to your graph in Fig. 2.1 at time t_d = 0.0 min.

Determine the gradient of this line, showing clearly how you did this.

Gradient = $\frac{33.00-20.00}{0.0-4.0}$
= −3.25 $cm^3\ min^{-1}$

Note: Must indicate it is a negative gradient

gradient = ...−3.25.... $cm^3\,min^{-1}$ [3]

(ii) Use your gradient to determine the rate of change of the amount of MnO_4^- ions required in $mol\,min^{-1}$.

Amt of MnO_4^- in 3.25 cm^3 = $\frac{3.25}{1000}$ × 0.0200 = 6.50 × 10^{-5}
Rate of change of amount of MnO_4^- ions = −6.50 × 10^{-5} mol min^{-1}

rate of change of the amount of MnO_4^- ions required = ...−6.50 × 10^{-5}.... $mol\,min^{-1}$ [1]

(iii) Determine the amount of H_2O_2 decomposed per minute and hence deduce the rate of change of $[H_2O_2]$ at t_d = 0.0 min, in $mol\,dm^{-3}\,min^{-1}$.

Amount of H_2O_2 decomposed per minute = (6.50 × 10^{-5}) × $\frac{5}{2}$ = 1.625 × 10^{-4} mol
Rate of change of $[H_2O_2]$ at t_d = 0.0 min = $\frac{1.625 \times 10^{-4}}{(10/1000)}$
= −0.01625 mol $dm^3\ min^{-1}$

(Only 10.0 cm^3 of reaction mixture is used for each titration with $KMnO_4$)

rate of change of $[H_2O_2]$ at t_d = 0.0 min = ...−0.0163.... $mol\,dm^{-3}\,min^{-1}$ [2]

(iv) It has been claimed that the decomposition of hydrogen peroxide is first order with respect to $[H_2O_2]$.

State whether you agree or disagree with this claim. Use evidence from your graph in Fig. 2.1 to support your answer.

Time taken for vol of **FA 3** to decrease from 25.00 cm^3 to 12.50 cm^3 = 6.0 min
Time taken for vol of **FA 3** to decrease from 20.00 cm^3 to 10.00 cm^3 = 6.0 min
Since vol of $KMnO_4$ used for each titration is directly proportional to the concentration of H_2O_2 in the reaction mixture, the shape of the $[H_2O_2]$ vs time graph will be similar to V_{KMnO4} vs time graph.
As $[H_2O_2]$ decreases with time, rate of reaction (gradient) also decreases with a constant half-life of 6.0 min.
Hence, decomposition of H_2O_2 is first order w.r.t. $[H_2O_2]$

.....

.....[2]

(c) Planning

The decomposition of hydrogen peroxide, shown in equation **1**, is also catalysed by the enzyme catalase, present in liver.

The rate equation for this decomposition is shown.

$$\text{rate} = k[H_2O_2][\text{catalase}]$$

If the concentration of the catalase is kept constant, the rate equation becomes

$$\text{rate} = k'[H_2O_2]$$

where $k' = k[\text{catalase}]$.

The activation energy, E_a, and the pre-exponential factor, A, which is a constant, can be determined from the equation.

$$k' = Ae^{\frac{-E_a}{RT}}$$

T is the reaction temperature in kelvin.
k' is the rate constant at a chosen temperature.

The procedure you followed in **2(a)(i)** can be modified to investigate the effect of temperature, T, on the rate of decomposition of H_2O_2. The activation energy, E_a, and the pre-exponential factor, A, can be graphically determined.

Plotting $\ln k'$ against $\frac{1}{T}$ gives a straight line of best fit. The gradient of this line is $\frac{-E_a}{R}$, where R is the molar gas constant.

(i) Plan an investigation, based on the experiment described in **2(a)(i)**, to determine the effect of temperature, T, on the rate of decomposition of H_2O_2 with catalase.

You may assume that you are provided with

- $500\,cm^3$ of $0.170\,mol\,dm^{-3}$ hydrogen peroxide, H_2O_2,
- a piece of liver,
- a scalpel (knife),
- $0.0200\,mol\,dm^{-3}$ potassium manganate(VII), $KMnO_4$,
- $0.2\,mol\,dm^{-3}$ sulfuric acid, H_2SO_4,
- the equipment normally found in a school or college laboratory.

In your plan you should include brief details of

- the reactants and conditions that you would use,
- the apparatus that you would use in addition to that specified in **2(a)(i)**,
- the procedure that you would follow and the measurements that you would take,
- how you would determine the initial rate for each experiment.

Thinking process:

In experiment 2(a), Fe^{3+} is the catalyst for the decomposition of H_2O_2, we are **replacing** Fe^{3+} with a piece of liver that contains catalase. The general procedures should still be similar to experiment 2(a).

Repeat experiment (minimum 5 experiments) with **varying temperatures** but other variables kept constant (such as size/amount/volume of liver used, volume of H_2O_2, volume of H_2SO_4 used to quench the reaction)

Procedure:

1. Using a 100 cm^3 measuring cylinder, measure 100 cm^3 of $H_2O_2(aq)$ and transfer into a 250 cm^3 conical flask labelled reaction mixture.
2. Place the conical flask into a thermostatically controlled water bath to maintain constant temperature of 30°C throughout the experiment.
3. Add a piece of 1cm × 1cm ×1cm liver to the same conical flask. Start the stopwatch and swirl the mixture thoroughly to mix its contents.
4. Using a 100 cm^3 measuring cylinder, measure and add 50.0 cm^3 of $H_2SO_4(aq)$ to a second 250 cm^3 conical flask.
5. Using a dropper, transfer a 10 cm^3 aliquot of the reaction mixture to a 10 cm^3 measuring cylinder.
6. Immediately transfer this aliquot into the second conical flask containing $H_2SO_4(aq)$ and vigorously swirl the mixture. Read and record the time of transfer in minutes and seconds, to the nearest second, when the aliquot is transferred.
7. Titrate this aliquot immediately with $KMnO_4(aq)$. The end point is reached when a permanent pale pink colour is obtained. Record the titration results.
8. Repeat steps 4 to 7 until a total of five aliquots have been titrated and their results recorded.
9. Repeat steps 1 to 8 using different temperatures of water bath, such as 35°C, 40°C, 45°C, 50°C
10. Plot graph of vol of $KMnO_4$ against time for the 5 experiments of different temperatures. Draw a tangent to each graph at time = 0 to find initial rate of reactions for the various temperature.

Temp /°C	Initial rate
30	
35	
40	
45	
50	

Important points to note:

* Constant mass/size of liver used

*Use a thermostatically controlled water bath to maintain temp of reaction mixture throughout each experiment.

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..... [7]

(ii) Briefly describe how you would use results obtained from **2(c)(i)** to determine all necessary values in order to plot a graph of ln k' against $\frac{1}{T}$.

You do **not** need to perform any of the calculations.

Calculate the gradient of the each of the 5 graphs. The gradient is the initial rate of each expt. $[H_2O_2]$ = 0.170 mol dm^{-3} as stated in the question.

Given that rate = k'$[H_2O_2]$, substitute the calculated rate and $[H_2O_2]$ to calculate k' for each expt. And we can obtain ln k'

Recordings of T must be converted to K, and we can calculate 1/T for all 5 experiments.

..... [2]

(iii) Sketch the graph you would expect to obtain from **2(c)(ii)** on the axes in Fig. 2.2.

Explain your answer.

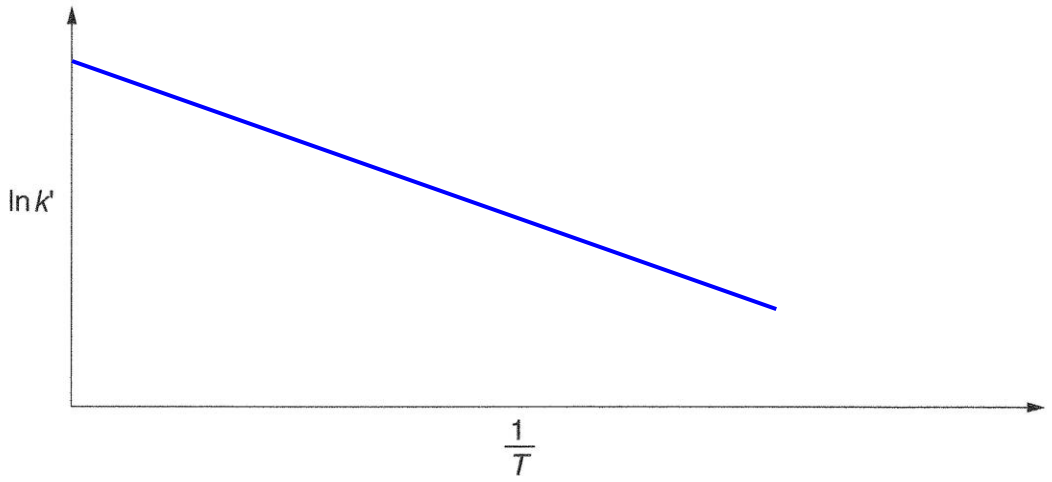

Fig. 2.2

explanation ln k' = ln A − $\frac{E_a}{R}\left(\frac{1}{T}\right)$

..... ln A is the y-intercept and − $\frac{E_a}{R}$ is the gradient of the straight line.

Since E_a and R are both positive values, the graph has a negative gradient

..... [2]

(iv) Describe how you would use your graph to determine values for E_a and A.

E_a Gradient of the line is − $\frac{E_a}{R}$. .....

Take gradient multiply by –R in order to find E_a.

....

.....

.....

A . Y-intercept is lnA. A = $e^{\text{y-intercept value}}$. .....

.....

.....

.....

[3]

[Total: 29]

3 Investigation of some redox reactions involving transition element ions

FA 5 is aqueous cobalt(II) chloride, $CoCl_2$.

(a) Perform the tests described in Table 3.1, and record your observations in the table. Test and identify any gases evolved. If there is no observable change, write **no observable change**.

Table 3.1

	tests	observations
1.	Add deionised water to a boiling tube until it is about one quarter full. Add aqueous sodium hydroxide to a second boiling tube until it is about one quarter full. Gently heat the second boiling tube until the liquid just starts to boil. Add one drop of **FA 3** to each boiling tube and shake them thoroughly. Observe the mixtures until no further changes are seen.	Addition of purple **FA 3** to deionised water gives a pink solution. Addition of purple **FA 3** is added to hot NaOH(aq) gives pink solution which turns blue then green.
While you are waiting, continue with test 2.		
2.	Add ten drops of **FA 5** to a test-tube. Add aqueous ammonia dropwise, with shaking, until no further change is seen. Then add about 1 cm depth of **FA 1** and shake the mixture thoroughly.	Addition of $NH_3(aq)$ to pink **FA 5**, a blue-green precipitate is formed, which dissolved partially in excess $NH_3(aq)$ to give a brown solution. When **FA 1** is added, vigorous effervescence of a colourless, odourless gas is observed, which relights a glowing splint. The gas is oxygen. The blue-green precipitate turns dark brown precipitate and the brown solution turns darker brown.

[4]

(b) Consider your observations in Table 3.1.

(i) A small amount of oxygen is produced in one of the boiling tubes used in test 1 in Table 3.1. It is unlikely that you will have noticed this.

Suggest an explanation for the colour changes you observed in test 1 in Table 3.1, in terms of the physical and chemical changes occurring.

Identify the boiling tube in which the oxygen is produced.

The boiling tube that contains hot aqueous NaOH with **FA 3** produces oxygen.

The colour changes observed (pink to blue to green) corresponds to chemical changes where MnO_4^- ions are being reduced by the OH^- ions while OH^- undergoes oxidation to produce oxygen gas.

The boiling tube that contains hot deionized water only gives an observation of purple to pink which corresponds to a physical change where purple $KMnO_4$ is diluted.

..... [2]

(ii) The original colour of **FA 5** is due to the presence of $[Co(H_2O)_6]^{2+}$ ions in the solution.

Identify, from your observations, the cobalt-containing species formed during test 2 in Table 3.1.

Pink $[Co(H_2O)_6]^{2+}$ formed blue precipitate, $Co(OH)_2$ when aqueous NH_3 is added which dissolves sparingly in excess NH_3 to give brown complex ion $[Co(NH_3)_6]^{2+}$

When H_2O_2 is added, blue precipitate, $Co(OH)_2$ is oxidized to brown ppt $Co(OH)_3$.
Brown complex ion $[Co(NH_3)_6]^{2+}$ is also oxidized to darker brown complex ion $[Co(NH_3)_6]^{3+}$

.....

.....

..... [2]

(iii) Compare the role of hydrogen peroxide in test 2 in Table 3.1 with its role in equation **2**, on page 8. Explain your answer in terms of oxidation state changes.

In test 2, H_2O_2 acts as an oxidising agent to oxidize Co^{2+} to Co^{3+}. The oxidation state of Co changes from +2(in Co^{2+}) to +3(in Co^{3+}).

In equation 2, H_2O_2 acts as a reducing agent to reduce MnO_4^- to Mn^{2+}. The oxidation state of Mn changes from +7(in MnO_4^-) to +2(in Mn^{2+}).

..... [1]

[Total: 9]