

# ANDERSON SERANGOON JUNIOR COLLEGE

## 2025 JC2 Preliminary Examination Paper 4 Solutions

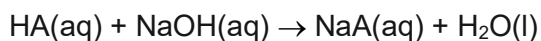
### 1 Determination of an enthalpy change of neutralisation, $\Delta H_{\text{neut}}$ , by thermometric titration

The enthalpy change of neutralisation between an acid and an alkali can be determined using thermometric titration. This involves using a fixed volume of alkali with progressive addition of small volumes of acid and monitoring the temperature of the reaction mixture during the process.

**FA 1** is an aqueous solution of  $1.80 \text{ mol dm}^{-3}$  of a monobasic acid, HA.

**FA 2** is aqueous sodium hydroxide, NaOH

You are to carry out a thermometric titration to determine the enthalpy change of neutralisation for the reaction given below.



Question continues on Page 4.

- (a) Prepare a table in the space provided and record, to appropriate level of precision:
- all volumes of **FA 1** added,  $V$
  - the maximum temperature,  $T$ , reached after each addition of **FA 1**.

It is important that the volume of **FA 1** recorded is the total volume you have added up to the point when the temperature reading was made.

Note: If you overshoot on an addition, record the actual total volume of **FA 1** added up to that point.

### Procedure

1. Place a polystyrene cup inside a second polystyrene cup and place both cups in a glass beaker.
2. Fill the burette with **FA 1**.
3. Use a measuring cylinder to transfer  $25\text{ cm}^3$  of **FA 2** into the polystyrene cup.
4. Stir the **FA 2** solution in the cup gently with the thermometer. Read and record its temperature.
5. Use the burette to add  $5.00\text{ cm}^3$  of **FA 1** into the cup. Stir the mixture gently with the thermometer. Read and record both the maximum temperature and the actual total volume of **FA 1** added.
6. Repeat step 5 until a total of  $45.00\text{ cm}^3$  of **FA 1** has been added. For each addition of **FA 1**, read and record both the maximum temperature and the actual total volume of **FA 1** added up to that point.

### Results

[1] correct headers + units

[1] records  $V$  to 2 d.p. and  $T$  to 1 d.p. (penalised students if recording last decimal recording is consistently .0 or .5 - competency in reading thermometer)

[1] complete set of readings that are of  $5.00\text{ cm}^3$  increment, inclusive of  $V = 0.00\text{ cm}^3$  and  $45.00\text{ cm}^3$

$V / \text{cm}^3$	$T / ^\circ\text{C}$
0.00	30.8
5.00	33.2
...	...
40.00	35.0
45.00	34.4

[3]

- (b) Plot a graph of temperature,  $T$ , on the y-axis, against total volume of **FA 1** added,  $V$ , on the x-axis on the grid in Fig.1.1. Your scale on the y-axis should allow for extrapolation above the highest temperature recorded.

Draw two lines of best fit, taking into account the points when the temperature of the mixture was rising and the points when the temperature was falling. Each line should have a shape best suited to its plotted points.

Extrapolate (extend) the two lines until they intersect.

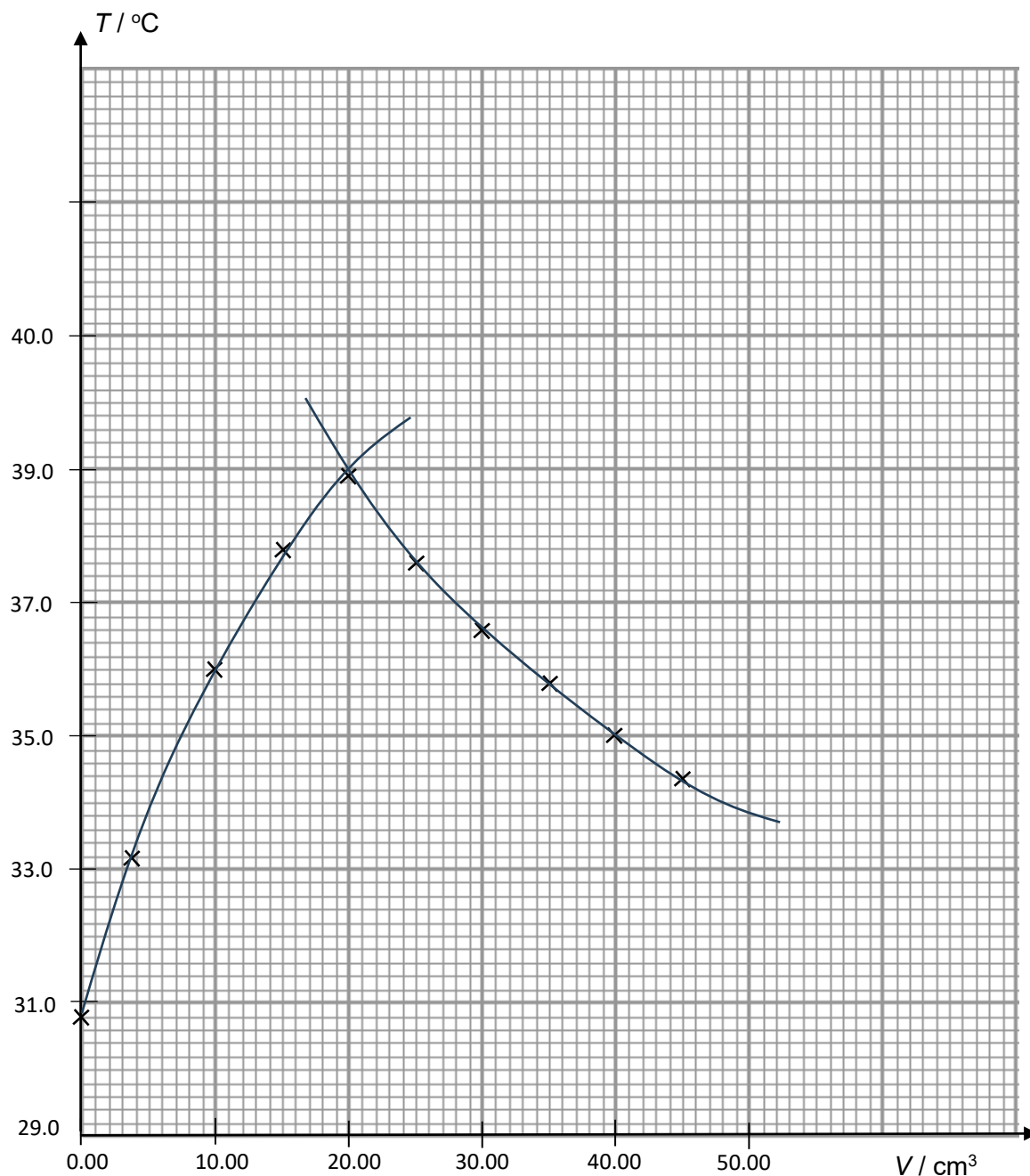


Fig. 1.1

- Axes correct way round + correct labels + units + scale (scale must be chosen to allow for the lines to be extrapolated to intersect)
- Graph has to occupy more than half the grid for both axes. **[1]**
- Plotting – all points including 0.00 cm<sup>3</sup> within  $\pm\frac{1}{2}$  small square. (select two from each side to check) **[1]**
- Both graph lines are best-fit lines **and** lines are correctly extrapolated to intersect **[1]**

[3]

- (c) From your graph, read the initial temperature of **FA 2**,  $T_{\text{initial}}$ , and the maximum temperature of the mixture,  $T_{\text{max}}$ .

Use these values to calculate the temperature change in the reaction,  $\Delta T$ .

Read the volume of **FA 1** added,  $V_{\text{neut}}$ , at the maximum temperature of the mixture.

Record all these values below.

$T_{\text{initial}} = \dots\dots\dots$

$T_{\text{max}} = \dots\dots\dots$

$\Delta T = \dots\dots\dots$

$V_{\text{neut}} = \dots\dots\dots$

[4]

- $T_{\text{initial}}$  and  $T_{\text{max}}$  correctly read from the graph to  $\pm\frac{1}{2}$  **small square**. **[2]**
- correct  $\Delta T$  calculated ( $T_{\text{initial}}$  may come from table or graph plot) **[1]**
- $V_{\text{neut}}$  correctly read from the graph to  $\pm\frac{1}{2}$  **small square**. **[1]**

- (d) (i) Using your answers from (c), calculate the heat change,  $q$ , when **FA 1** has completely neutralised 25 cm<sup>3</sup> of sodium hydroxide.

You should assume that the specific heat capacity of the solution is 4.18 J g<sup>-1</sup> K<sup>-1</sup>, and that the density of the solution is 1.00 g cm<sup>-3</sup>.

Total volume = 25 +  $V_{eq}$  (teacher value for  $V_{eq}$  is approximate 21 cm<sup>3</sup>)

Heat evolved,  $q = mc\Delta T$

$$= (V_{eq} + 25) \text{ cm}^3 \times 1.00 \text{ g cm}^{-3} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times \Delta T \text{ J} \quad [1]$$

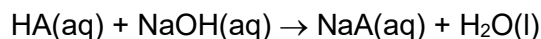
- correct substitution of total volume
- correct substitution of values into  $mc\Delta T$  (allow ecf)

[1] Correct calculation of  $q$

$$q = \dots\dots\dots [2]$$

- (ii) Calculate the enthalpy change of neutralisation,  $\Delta H_{neut}$ , for the reaction.

The equation for the reaction is shown.



Include the sign of  $\Delta H_{neut}$  in your answer.

No of moles of water = no of moles of HA =  $1.80 \times (V_{eq} / 1000)$

$$\begin{aligned} \Delta H_{neut} &= - (q \div \text{moles of water}) \\ &= - (\text{d})(i) \div n(\text{water}) \text{ J mol}^{-1} \end{aligned}$$

[1]  $n(\text{water})$  formed

[1] working to find  $\Delta H_{neut}$  (allow ecf)

[1] answer (if no negative sign, no marks)

[1] 3 s.f. and correct units for (d)(i) & (ii)

$$\Delta H_{neut} = \dots\dots\dots [4]$$

- (e) Apart from using a thermometer with a greater level of precision, suggest one improvement that could be made to improve the accuracy of results in (d)(ii).

Use a burette / pipette to measure volume of FA 2 / cover with lid / use smaller volumes close to  $T_{\max}$  / use windshield. [1]

[1]

- (f) A student decided to perform the same experiment in (a) but used aqueous ammonia instead of aqueous sodium hydroxide.

Suggest what effect, if any, would replacing aqueous sodium hydroxide with aqueous ammonia have on the value of enthalpy change of neutralisation calculated in (d)(ii).

effect .....

The value of enthalpy change of neutralisation will be **smaller in magnitude / less exothermic**. [1]

explanation .....

.....  
Aqueous ammonia is a weak base. Some of the **energy released from neutralisation will be absorbed to cause the (complete) dissociation of ammonia**, resulting in the overall heat released to be smaller. [1]

[2]

[Total: 19]

## 2 Determination of the amount of water of crystallisation in sodium sulfite crystals, $\text{Na}_2\text{SO}_3 \cdot x\text{H}_2\text{O}$

**FA 3** is an aqueous solution of  $126.0 \text{ g dm}^{-3}$  of hydrated sodium sulfite with the formula  $\text{Na}_2\text{SO}_3 \cdot x\text{H}_2\text{O}$ .

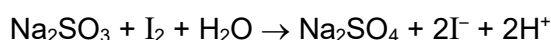
**FA 4** is  $0.100 \text{ mol dm}^{-3}$  iodine,  $\text{I}_2$ .

**FA 5** is  $0.100 \text{ mol dm}^{-3}$  sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3$ .

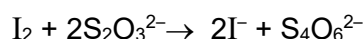
You are also provided with **Solution S**.

Solid sodium sulfite is often provided as the hydrated salt,  $\text{Na}_2\text{SO}_3 \cdot x\text{H}_2\text{O}$ , where  $x$  is an integer.

You will determine the value of  $x$  by using a solution of this sodium sulfite salt and reacting it with an excess of aqueous iodine.



The amount of iodine remaining will be determined by titration using a known concentration of sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3$ .



### (a) (i) Dilution of **FA 3**

**FA 3** is too concentrated and needs to be diluted.

Use a burette to transfer  $25.00 \text{ cm}^3$  of **FA 3** into a  $100 \text{ cm}^3$  volumetric flask.

Make the solution up to the mark with deionised water. Label this solution **FA 6**.

### Titration of **FA 6** against **FA 5**

1. Fill the burette with **FA 5**.
2. Use a pipette to transfer  $10.0 \text{ cm}^3$  of **FA 6** into a  $250 \text{ cm}^3$  conical flask.
3. Use another pipette to transfer  $25.0 \text{ cm}^3$  of **FA 4** into the same conical flask.
4. Swirl the flask to mix the contents.
5. Run **FA 5** from the burette into the conical flask. Near the end-point, when the brown solution becomes pale, add about 10 drops of **Solution S** using a teat pipette.
6. Continue adding **FA 5**. The end-point is reached when the solution first becomes colourless.
7. Record your titration results, to an appropriate level of precision, in the space provided on page 9.
8. Discard the reaction mixture.
9. Repeat steps 2 to 8 until consistent results are obtained.

**Titration results**

Titration number	1	2
Final burette reading / cm <sup>3</sup>		
Initial burette reading / cm <sup>3</sup>		
Volume of <b>FA 5</b> used / cm <sup>3</sup>		

**[1]** Table has correct headers and units.  
 Tabulation may be vertical or horizontal; lines are not essential but there should be no absences of headers.  
 Where units have not been included in the header, there should be the appropriate unit for **each entry** in each table.  
 Do NOT award this mark if any final and initial burette readings are inverted or 50 is used as the initial burette reading.

**[1]** All accurate burette readings are recorded to the nearest 0.05 cm<sup>3</sup> (2 d.p.)  
*Treat all titres as “accurate” unless labelled rough or 1<sup>st</sup> titre is to lower precision than subsequent titres*

**[1]** Has at least two consistent titres for end-point within 0.10 cm<sup>3</sup> and correct volume of FA5 used correctly calculated for each experiment.

[3]

- (ii) From your titrations, obtain a suitable volume of **FA 5** to be used in your calculations. Show clearly how you obtained this volume.

Volume of **FA 5** = .....cm<sup>3</sup> [3]

**[1]** Student obtains an appropriate “average” from uncorrected titre values within a 0.20 cm<sup>3</sup> range **and** Answer has to be in 2 d.p..  
*Do not award this mark if the titre values used are not identified either in the table (by, for example, a tick) or in a calculation.*

**Accuracy [2]**

Check and correct titre subtractions where necessary. To select the best titres for calculating the mean, using the hierarchy.

**Hierarchy to be used in calculating mean titres**

- Value of 2 identical titres
- Average of titres within 0.05 cm<sup>3</sup>
- Average of titres within 0.1 cm<sup>3</sup>, etc

Examiner subtracts (corrected) candidate's titre from Supervisor's titre.

**[2]** difference titre is  $\leq 0.20$  cm<sup>3</sup>

**[1]**  $0.3 \leq \text{difference} > 0.20$  cm<sup>3</sup>



<b>SHIFT 1</b>	
<b>Titre 1</b>	<b>24.55</b>
<b>Titre 2</b>	<b>24.60</b>
<b>AVERAGE</b>	<b>24.58</b>
<b>RANGE (2m)</b>	<b>24.38 - 24.78</b>
<b>RANGE (1m)</b>	<b>24.28 - 24.38 / 24.78 - 24.88</b>

<b>SHIFT 2</b>	
<b>Titre 1</b>	<b>24.20</b>
<b>Titre 2</b>	<b>24.30</b>
<b>AVERAGE</b>	<b>24.25</b>
<b>RANGE (2m)</b>	<b>24.05 - 24.45</b>
<b>RANGE (1m)</b>	<b>23.95 - 24.05 / 24.45 - 24.55</b>

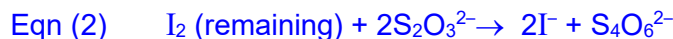
<b>SHIFT 3</b>	
<b>Titre 1</b>	<b>24.40</b>
<b>Titre 2</b>	<b>24.35</b>
<b>AVERAGE</b>	<b>24.38</b>
<b>RANGE (2m)</b>	<b>24.18 - 24.58</b>
<b>RANGE (1m)</b>	<b>24.08 - 24.18 / 24.58 - 24.68</b>

- (b) (i) Calculate the amount in moles of iodine present in 25.0 cm<sup>3</sup> of **FA 4** added to the conical flask. [1]

Amount of iodine (initial) added to the conical flask

$$= \frac{25}{1000} \times 0.1 = 0.00250 \text{ mol [1]}$$

- (ii) Use your titration results to calculate the amount of excess iodine after reaction with sodium sulfite in the conical flask. Hence, calculate the amount of iodine that reacted with 10.0 cm<sup>3</sup> of **FA 6**. [3]



(Assuming teacher value to be 24.80 cm<sup>3</sup>)

$$\begin{aligned} \text{Amount of sodium thiosulfate} &= 24.80/1000 \times 0.100 \\ &= 0.00248 \text{ mol [1]} \end{aligned}$$

From Eqn (2)

$$\begin{aligned} \text{Amount of iodine (remaining) in the conical flask} &= 0.00248/2 \\ &= \underline{0.00124 \text{ mol [1]}} \end{aligned}$$

$$\text{amount of excess iodine after reaction with sodium sulfite} = \underline{0.00124 \text{ mol}}$$

$$\begin{aligned} \text{Amount of iodine reacted with sulfite in } 10.0 \text{ cm}^3 \text{ of FA 6 (diluted FA 3)} \\ = 0.0025 - 0.00124 = \underline{0.00126 \text{ mol [1]}} \end{aligned}$$

$$\text{amount of iodine that reacted with } 10 \text{ cm}^3 \text{ of FA 6} = \underline{0.00126 \text{ mol}}$$

- (iii) Calculate the amount of sodium sulfite present in 25 cm<sup>3</sup> of **FA 3** and find the value of x in Na<sub>2</sub>SO<sub>3</sub>·xH<sub>2</sub>O. [2]



$$\text{Amount of Na}_2\text{SO}_3 \text{ present in } 10.0 \text{ cm}^3 \text{ FA 6 (diluted FA 3)} = 0.00126 \text{ mol}$$

$$\begin{aligned} \text{Amount of Na}_2\text{SO}_3 \text{ present in } 100 \text{ cm}^3 \text{ FA 6 (diluted FA 3)} \\ = (100/10) \times 0.00126 = 0.0126 \text{ mol [1]} \end{aligned}$$

$$\begin{aligned} \text{Amount of Na}_2\text{SO}_3 \text{ present in } 100 \text{ cm}^3 \text{ volumetric flask} \\ = \text{amount of Na}_2\text{SO}_3 \text{ in } 25 \text{ cm}^3 \text{ of FA 3} \\ = 0.0126 \text{ mol (since dilution will not affect the amount in moles) [1]} \end{aligned}$$

- (iv) Determine the value of x in Na<sub>2</sub>SO<sub>3</sub>·xH<sub>2</sub>O. [4]  
[A<sub>r</sub>: H, 1.0; O, 16.0; Na, 23.0; S, 32.1]

$$\text{Mass of Na}_2\text{SO}_3 \text{ in } 25.0 \text{ cm}^3 \text{ of FA 3} = \frac{25}{1000} \times 126.0 = 3.15 \text{ g [1]}$$

$$\text{Molar mass} = \frac{3.15}{0.0126} = 250.0 \text{ [1]}$$

$$2(23.0) + 32.1 + 3(16.0) + (x)(2 \times 1.0) + x(16.0) = 250.0$$

$$x = 7 \text{ (whole number) [1]}$$

**[1]** Shows working in **all** calculations **and**

Shows appropriate significant figures (3 or 4 sf), in **all** final answers **and** shows appropriate units in **all** final answers.

*Any calculation not attempted loses this mark.*

*All calculations must be relevant although they may not be complete or correct.*

- (c) Most of the pipettes used in school or college laboratories have uncertainties (errors) of  $\pm 0.03 \text{ cm}^3$ .

Calculate the percentage error of the volumes measured by the pipettes you used in (a)(i).

Hence, state how the percentage uncertainty of a volume measured depends on the capacity of the pipette used. [1]

Student calculates percentage uncertainty to be

• for the  $10 \text{ cm}^3$  pipette =  $0.03/10.0 \times 100 = 0.30\%$

• for the  $25 \text{ cm}^3$  pipette =  $0.03/25.0 \times 100 = 0.12\%$

The percentage uncertainty **decreases** as the pipette volume **increases** (or vice versa). [1]

- (d) Devise a simple test to confirm the presence of sulfite ions in **FA 3** solution. Your test should be based on Qualitative Analysis Notes on pages 19 -20. You do NOT need to perform the test. [1]

To  $1 \text{ cm}^3$  sample of **FA 3** in a test tube, **add**  $1 \text{ cm}^3$  of **HC / HNO<sub>3</sub> / H<sub>2</sub>SO<sub>4</sub>**.

**Test the gas evolved** (with filter paper soaked) **with aqueous acidified potassium manganate(VII)**.

(If filter paper turns from purple to colourless, sulfite is present.)

**Alternative**

To  $1 \text{ cm}^3$  sample of **FA 3** in a test tube, **add**  $1 \text{ cm}^3$  of **Ba(NO<sub>3</sub>)<sub>2</sub>**.

Add dilute **HC/HNO<sub>3</sub>** slowly until no further change.

(White precipitate dissolves in excess acid.)

[Total: 18]

### 3 (a) Organic Analysis

**Before starting this analysis, please ensure that your Bunsen burner is turned off.**

You are provided with the organic liquid samples of **FA 7**, **FA 8**, **FA 9** and **FA 10** with the molecular formulae shown.

- **FA 7**      $\text{C}_3\text{H}_6\text{O}$
- **FA 8**      $\text{C}_3\text{H}_6\text{O}$
- **FA 9**      $\text{C}_3\text{H}_8\text{O}$
- **FA 10**    $\text{C}_3\text{H}_6\text{O}_2$

You will perform some the tests described in Table 3.1.

Using the observations in Table 3.1, and the given molecular formulae, you will then deduce the identities of **FA 7**, **FA 8**, **FA 9** and **FA 10**.

In addition to having access to the usual bench reagents, you are also provided with the following:

- iodine solution, **FA 4**
  - Fehling's solution
  - 2,4-dinitrophenylhydrazine
  - sodium carbonate
- (i) Perform the tests described in Table 3.1. Some tests have already been carried out and the observations have been recorded in the table. There is no need to carry out those tests.

Test and identify any gases evolved. If there is no observable change, record **no observable change**.

**Use a fresh sample of each liquid in each test.**

Table 3.1

tests	observations with			
	FA 7 propanone	FA 8 propanal	FA 9 propan-2-ol	FA 10 propanoic acid
<p>1. Add 5 drops of organic liquid into a clean test-tube.</p> <p>To this test-tube, add about 1 cm depth of Fehling's solution. Prepare a hot water bath. Warm the mixture for about 2 minutes.</p>	No observable change	Brick red ppt / dark orange ppt / red brown ppt [✓]  yellow ppt unacceptable	No observable change/ No ppt/ No brick red ppt [✓]	No observable change
<p>2. To a 1 cm depth of the organic liquid in a test-tube, add a few drops of 2,4-DNPH.</p>	Orange/yellow ppt observed [✓]	Orange ppt observed	No observable change	No ppt / No observable change [✓]
<p>3. To a 1 cm depth of aqueous sodium hydroxide in a test-tube, add 1 cm depth of iodine solution, FA 4. Then add three drops of the organic liquid. Warm the mixture for about 2 minutes.</p>	Yellow ppt [✓]	No observable change	Yellow ppt [✓]	No observable change
<p>4. Place about 1 cm depth of the organic liquid in a test-tube.</p> <p>To this test-tube, add about 1 cm depth of aqueous sodium carbonate.</p>	No observable change [✓]	No observable change	No observable change	Effervescence observed  CO <sub>2</sub> gas form white ppt in lime water [✓]
<p>5. Place about 1 cm depth of dilute sulfuric acid in a test-tube. Then add 2 drops of potassium manganate(VII).</p> <p>To this test-tube, add 3 cm depth of organic liquid.</p> <p>Shake and warm the test-tube in a water-bath.</p>	No observable change	Purple KMnO <sub>4</sub> decolourises	Purple KMnO <sub>4</sub> decolourises	No observable change

[3]

7 to 8 [✓] → [3]

5 to 6 [✓] → [2]

4 [✓] → [1]

- (ii) Complete Table 3.2, with the identities of **FA 7**, **FA 8**, **FA 9** and **FA 10**. Give evidence from relevant observations in Table 3.1 to support your conclusions. You should also include deductions of functional groups or structural features for the observations.

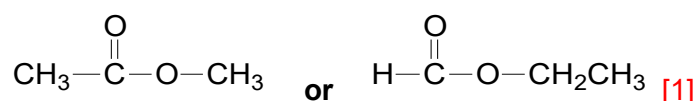
Table 3.2

	identity	evidence
<b>FA 7</b>	propanone	<ul style="list-style-type: none"> <li>• <u>Orange ppt form with 2,4-DNPH</u>, presence of <u>carbonyl</u> functional group</li> <li>AND</li> <li>• <u>Yellow ppt with alkaline aqueous iodine</u>, presence of <math>\text{R}-\overset{\text{O}}{\underset{\text{  }}{\text{C}}}-\text{CH}_3</math></li> </ul>
<b>FA 8</b>	propanal	<ul style="list-style-type: none"> <li>• <u>Brick-red ppt with Fehling's</u>, presence of <u>aldehyde</u> functional group</li> </ul>
<b>FA 9</b>	propan-2-ol	<ul style="list-style-type: none"> <li>• <u>Purple <math>\text{KMnO}_4</math> decolourised</u>, presence of <u>primary or secondary alcohol (do not accept alcohol)</u></li> <li>AND</li> <li>• <u>Yellow ppt with alkaline aqueous iodine</u>, presence of <math>\text{R}-\overset{\text{OH}}{\underset{\text{H}}{\text{C}}}-\text{CH}_3</math></li> </ul>
<b>FA 10</b>	propanoic acid	<ul style="list-style-type: none"> <li>• <u>Effervescence observed with sodium carbonate</u>, presence of <u>carboxylic acid</u></li> </ul>

[4]

Any 2 points → [1]

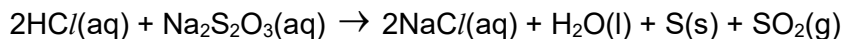
- (iii) **FA 11** is an isomer of **FA 10**.  
**FA 11** is neutral and have a sweet odour.  
 Suggest a structural formula of **FA 11**. [1]



[Total: 8]

#### 4 Planning

The activation energy,  $E_a$ , for the reaction between dilute hydrochloric acid,  $\text{HCl}(\text{aq})$ , and aqueous sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ , can be determined by a 'sulfur clock' method.



The solid sulfur formed is seen as a pale-yellow suspension in the reaction mixture. The reactants are mixed and the time taken,  $t$ , for a fixed quantity of sulfur to be formed and obscure a laminated insert is recorded.

A measure of the initial rate of the reaction is  $\frac{1}{t}$ .

The activation energy,  $E_a$ , for the reaction may be determined by measuring the time for a fixed quantity of sulfur to obscure a laminated insert at different temperatures.

You may assume you are provided with:

- 600  $\text{cm}^3$  glass beaker
- laminated insert
- 65  $\text{cm}^3$  0.100  $\text{mol dm}^{-3}$   $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$
- 65  $\text{cm}^3$  0.500  $\text{mol dm}^{-3}$   $\text{HCl}(\text{aq})$
- the equipment normally found in a school or college laboratory

In order to calculate  $E_a$ , the following equation is used.

$$\ln\left(\frac{1}{t}\right) = \frac{-E_a}{R} \left(\frac{1}{T}\right) + c$$

where  $R$  is the molar gas constant  
and  $c$  is a constant for the reaction.

**(a)** Plan an experiment to collect 5 sets of data to plot a graph of  $\ln(1/t)$  against  $1/T$  where

- $t$  is the time for the laminated insert to be obscured
- $T$  is the reaction temperature in kelvin.

In your plan, you should use the solutions provided. The concentrations of the 2 reactants are chosen so that mixing equal volumes of them gives a mixture with a suitable mole ratio for this method.

Your plan should include brief details of

- the apparatus you would use
- the procedure you would follow
- the measurements you would take
- how the data measured would be used to determine values needed for the plotting of the graph.

[8]

### Procedure

1. Using a **600 cm<sup>3</sup> beaker**, **prepare a water bath** of approximately **30 °C** by mixing tap water with hot water from a hot water dispenser. Use a **thermometer** to monitor its temperature.
2. Using a **10 cm<sup>3</sup> measuring cylinder**, add **10 cm<sup>3</sup>** of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>(aq) to a clean **boiling tube**. This is solution 1.
3. Using another **10 cm<sup>3</sup> measuring cylinder**, **measure 10 cm<sup>3</sup>** of HCl(aq) into another clean **boiling tube**. This is solution 2.
4. Clamp/**Secure both boiling tubes** to the retort stand and **leave it inside the water bath**.
5. **Place a thermometer into each of the boiling tube**.
6. Place the **laminated insert behind** the 600 cm<sup>3</sup> beaker.
7. When **temperature of reaction mixture in both boiling tube is within about 1 °C of that of the water bath**, **pour** solution 2 **rapidly into the boiling tube containing** solution 1.
8. **Start the stopwatch** when about **half of solution 2** has been added.
9. **Stir the mixture** using the thermometer in the boiling tube.
10. **Stop the stopwatch** when the **laminated insert is obscured**.
11. **Record the time taken,  $t$**  and the **temperature,  $T_K$ , in kelvin, of the reaction mixture**.
12. **Discard** the reaction mixture **immediately** down the sink.
13. **Wash** the thermometer in the boiling tube with water and dry it on paper towel. Wash the boiling tubes.
14. **Repeat points 1 to 12 for four more temperatures** (40 °C, 50 °C, 60 °C and 70 °C).

### Measurements

1. Calculate  $\frac{1}{t}$  and  $\frac{1}{T_K}$  K<sup>-1</sup>
2. Plot a graph of  $\ln\left(\frac{1}{t}\right)$ , on the y-axis, against  $\frac{1}{T_K}$ , on the x-axis.
3. Draw a straight line of best fit, taking into account all of your plotted points.

[Total: 8]



Expt	Vol. of $\text{Na}_2\text{S}_2\text{O}_3 / \text{cm}^3$	Vol. of $\text{HCl} / \text{cm}^3$	$t / \text{min}$	$T_K / \text{K}$	$\frac{1}{T_K} / \text{K}^{-1}$	$\frac{1}{t} / \text{min}^{-1}$	$\ln \frac{1}{t}$
1	10.0	10.0					
2	10.0	10.0					
3	10.0	10.0					
4	10.0	10.0					

- (b) (i) Sketch the graph that you would expect to obtain on the axes in Fig. 4.1.

The equation for the graph is

$$\ln\left(\frac{1}{t}\right) = \frac{-E_a}{R} \left(\frac{1}{T}\right) + c$$

where  $R$  is the molar gas constant  
and  $c$  is a constant for the reaction.

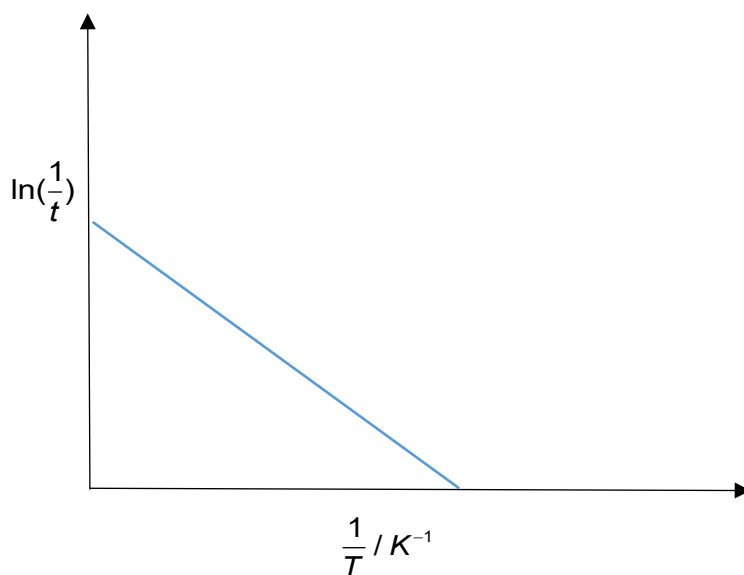


Fig. 4.1

[1]

- (ii) Describe how you will use your graph to determine the value of  $E_a$ . [1]

Find 2 points on the graph and read off the coordinates  $(x_1, y_1)$  and  $(x_2, y_2)$ .

$$\begin{aligned} \text{Gradient} &= \frac{y_2 - y_1}{x_2 - x_1} \quad \text{OR} \quad \text{Gradient} = \frac{\Delta \ln\left(\frac{1}{t}\right)}{\Delta\left(\frac{1}{T}\right)} \\ &= -\frac{E_a}{R} \\ E_a &= -R \times \text{gradient} \quad [1] \end{aligned}$$

Note: Since the question asked to “Describe how you would use your graph”, it will be good to also explain how the gradient is obtained.

[Total: 10]

**Detailed Mark Scheme – [9]**

Apparatus [1]	<p>All 5 types of apparatus regardless of procedure</p> <ul style="list-style-type: none"> <li>• beaker used for water bath</li> <li>• 10 cm<sup>3</sup> measuring cylinders</li> <li>• Boiling tube</li> <li>• Stopwatch</li> <li>• Thermometers (one for the water bath, at least one for the main reaction mixture)</li> </ul> <p><b>**Direct heating with Bunsen flame/hotplate is NOT accepted as it does not allow evenly heating of reaction mixture.</b></p>
Procedure [2]	<p><b>[1]</b> (before mixing)</p> <ul style="list-style-type: none"> <li>• Prepare a water bath (no need to state the different temperatures required).</li> <li>• Measure AND transfer both sets of chemicals into the 2 separate boiling tubes.</li> <li>• Leave both boiling tubes with thermometer inside the water bath to allow them to equilibrate to the correct temperature up to the point before mixing.</li> </ul> <p><b>[1]</b> (mixing)</p> <ul style="list-style-type: none"> <li>• Transfer solution 2 into solution 1.</li> <li>• Start the stopwatch.</li> <li>• Stop the stopwatch when the reaction mixture obscures the insert.</li> <li>• Pour away reaction mixture.</li> <li>• Repeat experiments by varying only the temperatures (need not state the temperatures used) but keeping volumes constant.</li> </ul>
Reliability/ Safety [1]  (Any 3 points - 1 mark)	<ul style="list-style-type: none"> <li>• Monitor temperature of water bath using thermometer.</li> <li>• Start mixing when temperature of reaction mixture in boiling tube is within about 1 °C of that of the water bath/ after 10 minutes.</li> <li>• <u>Transfer</u> solution 2 <b>rapidly</b> from the test-tube, into the boiling tube.</li> <li>• <b><u>Start the stopwatch</u></b></li> <li>• Stir the mixture using thermometer.</li> </ul>
Measurements/ Recordings [3]	<p>To mention in words and/or show in table format.</p> <p><b>[1] Appropriate suggested volume for each reagent</b> which remains a constant for all the experiments. Eg: 10 cm<sup>3</sup> of EACH of the reagents used for each experiment.</p> <ul style="list-style-type: none"> <li>○ Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub></li> <li>○ HCl</li> </ul> <p><u>How to derive volume used</u></p> <p>Since volume of reagents provided is 65 cm<sup>3</sup> each, and a minimum of 5 experiments should be conducted to provide</p>

	<p>sufficient data for graph and ensure reliability, maximum volume of each reagent used in every experiment</p> $= \frac{65}{\text{no. of proposed experiments}}$ <p><math>\approx \text{max } 15 \text{ cm}^3</math></p> <p>Rounding down to nearest <math>10 \text{ cm}^3</math> gives a good volume without exceeding the total <math>65 \text{ cm}^3</math> total)</p> <p>Note: Read question carefully to keep to maximum of <math>65 \text{ cm}^3</math> for each chemical and use equal volumes of all chemicals in each experiment.</p> <p>[1]</p> <ul style="list-style-type: none"> <li>• <b>Temperature of the reaction mixture</b> <ul style="list-style-type: none"> <li>○ Experiment conducted with at least 5 different temperatures with a good spread, at least <math>5^\circ\text{C}</math> between each temperature (E.g.: <math>30^\circ\text{C}</math>, <math>40^\circ\text{C}</math>, <math>50^\circ\text{C}</math>, <math>60^\circ\text{C}</math> and <math>70^\circ\text{C}</math>)</li> <li>○ Temperature chosen should be sound and within the range that water remains a liquid. (i.e. Temperatures too close to freezing and boiling point of water or any of the chemicals will not be accepted. i.e: Min temperature <math>25^\circ\text{C}</math>, max <math>90^\circ\text{C}</math>).</li> </ul> </li> </ul> <p>[1]</p> <ul style="list-style-type: none"> <li>• <b>Time taken for the laminated insert to be obscured.</b> (Accept in minutes or seconds)</li> </ul>
Use of Data measured [1]	<ul style="list-style-type: none"> <li>• Convert temperature of reaction mixture from <math>^\circ\text{C}</math> to Kelvin/</li> <li>• Calculate <math>\frac{1}{t}</math> and <math>\frac{1}{T_K} / \text{K}^{-1}</math></li> </ul> <p>Note: Follow the units stipulated by question. However, do note that our thermometer readings are in <math>^\circ\text{C}</math> and extra step needed to indicate conversion to kelvin for this question.</p>

END