



**NAMIBIA UNIVERSITY  
OF SCIENCE AND TECHNOLOGY**

**FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT**

**InSTEM**

<b>QUALIFICATION: INTRODUCTION TO SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS</b>	
<b>QUALIFICATION CODE: 04STEM</b>	<b>LEVEL: 4</b>
<b>COURSE CODE: ICH402S</b>	<b>COURSE NAME: INTRODUCTION TO CHEMISTRY B</b>
<b>SESSION: NOVEMBER 2022</b>	<b>PAPER: N/A</b>
<b>DURATION: 3 HOURS</b>	<b>MARKS: 100</b>

<b>FIRST OPPORTUNITY EXAMINATION PAPER</b>	
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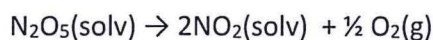
<b>INSTRUCTIONS</b>
<ol style="list-style-type: none"><li>1. Answer all questions.</li><li>2. Write all the answers in ink.</li><li>3. No books, notes, correction fluid (Tippex) or cell phones allowed.</li><li>4. Pocket calculators are allowed.</li><li>5. You are not allowed to borrow or lend any equipment or stationary.</li><li>6. Periodic Table on page 12</li></ol>

**THIS EXAMINATION PAPER CONSISTS OF 12 PAGES (Excluding this front page)**



**Question 1****[15]**

Dinitrogen pentoxide,  $\text{N}_2\text{O}_5$ , is dissolved in an inert solvent (solv) and the rate of decomposition of  $\text{N}_2\text{O}_5$  is investigated. This reaction produces nitrogen dioxide, which remains in solution, and oxygen gas.

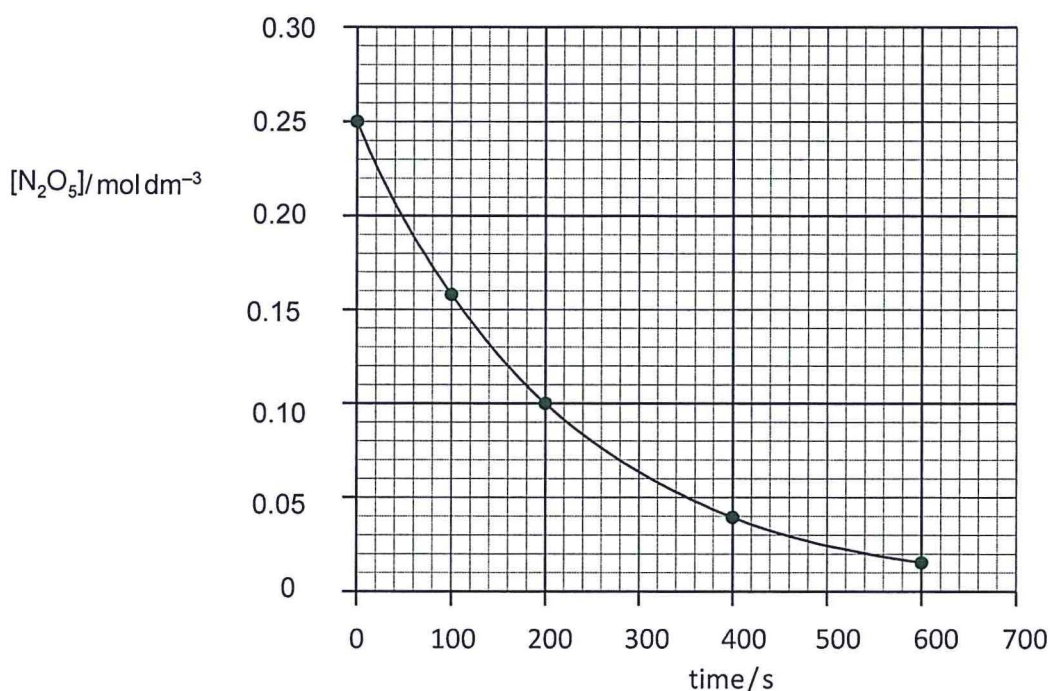


1.1 Suggest what measurements could be used to follow the rate of this reaction from the given information. (1)

1.2 In a separate experiment, the rate of the decomposition of  $\text{N}_2\text{O}_5(\text{g})$  is investigated.



The graph below shows the results obtained:



The reaction is first order with respect to  $\text{N}_2\text{O}_5$ . This can be confirmed from the graph using half-lives.

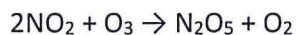
- 1.2.1 Explain the term half-life of a reaction. (1)
- 1.2.2 Determine the half-life of this reaction. (1)
- 1.2.3 Suggest the effect on the half-life of this reaction if the initial concentration of  $\text{N}_2\text{O}_5$  is halved. (1)
- 1.2.4 Use the graph in 1.2 to determine the rate of reaction at 200 s. Show your working and the unit. (2)



The rate equation for this reaction is shown:  $\text{rate} = k [\text{N}_2\text{O}_5]$

- 1.2.5 Use your answer to 1.2.4 to calculate the value of the rate constant,  $k$ , for this reaction and state its units. (1)

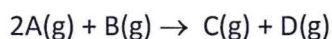
- 1.3 Nitrogen dioxide reacts with ozone,  $\text{O}_3$ , as shown:



The rate equation for this reaction is  $\text{rate} = k [\text{NO}_2][\text{O}_3]$ .

Suggest a possible two-step mechanism for this reaction. (2)

- 1.4 Gases **A** and **B** react as shown in the following equation:



The initial rate of the reaction was measured in a series of experiments at a constant temperature. The following rate equation was determined:

$$\text{rate} = k[\text{A}]^2$$

An incomplete table of data for the reaction between A and B is shown in the Table below.

Experiment	Initial [A] / mol dm <sup>-3</sup>	Initial [B] / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	$4.2 \times 10^{-3}$	$2.8 \times 10^{-3}$	$3.3 \times 10^{-5}$
2	$7.9 \times 10^{-3}$	$2.8 \times 10^{-3}$	
3		$5.6 \times 10^{-3}$	$1.8 \times 10^{-4}$

- 1.4.1 Use the data from Experiment 1 to calculate a value for the rate constant,  $k$ , at this temperature. What is the units of  $k$ ? (3)

- 1.4.2 Use your value of  $k$  from Question 1.4.1 to complete the Table for the reaction between A and B.  
(If you have been unable to calculate an answer for Question 1 (a), you may assume a value of 2.3 This is not the correct answer.) (2)

- 1.4.3 The reaction is zero order with respect to B. State the significance of this zero order for the mechanism of the reaction. (1)



**Question 2****[15]**

When dilute sulfuric acid is electrolysed, water is split into hydrogen and oxygen.



A current of  $x$  A is passed through the solution for 14.0 minutes.  $462 \text{ cm}^3$  of hydrogen are produced at the cathode, measured under room conditions.

- 2.1 Calculate the number of hydrogen molecules produced during the electrolysis. (2)
- 2.2 Calculate the total number of electrons transferred to produce this number of hydrogen molecules. (1)
- 2.3 Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in 2.2. (1)
- 2.4 Calculate the current,  $x$ , passed during this experiment. (1)
- 2.5 The standard entropies,  $\Delta S^\ominus$ , of three species are given in the table.

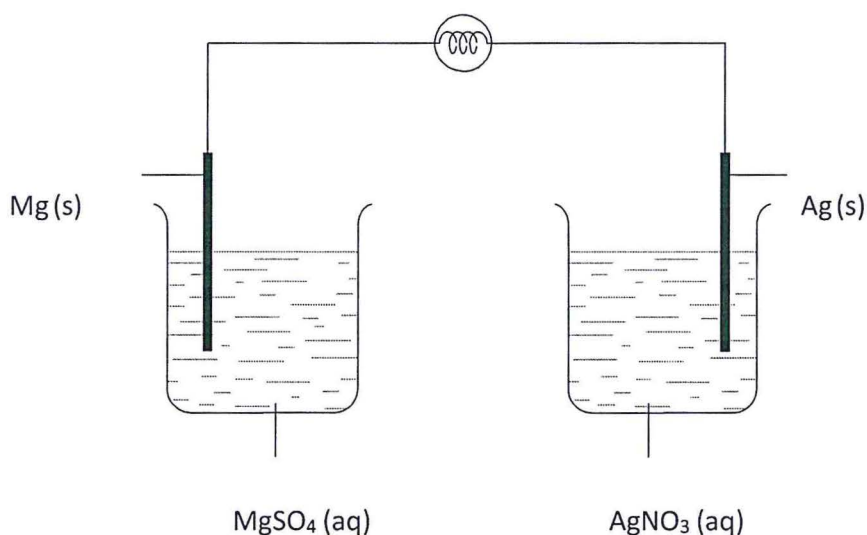
species	$S^\ominus/\text{JK}^{-1} \text{ mol}^{-1}$
$\text{H}_2\text{O}(\text{l})$	+70
$\text{H}_2(\text{g})$	+131
$\text{O}_2(\text{g})$	+205

- 2.5.1 Calculate  $\Delta S^\ominus$  for the reaction  $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$ . (1)
- 2.5.2  $\Delta H^\ominus$  for the reaction  $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$  is  $+572 \text{ kJ mol}^{-1}$ . Calculate  $\Delta G^\ominus$  for this reaction at 298 K. (2)
- 2.5.3 Predict the effect of increasing temperature on the spontaneity of this reaction. Explain your answer. (1)





2.6 The diagram shows an incomplete voltaic cell with a light bulb in the circuit.



2.6.1 Identify the missing component of the cell and its function. (2)

2.6.2 Deduce the half-equations for the reaction at each electrode when current flows. (2)

2.6.3 Redraw the diagram with the location and direction of electron movement when current flows. (1)

2.6.4 Calculate the cell potential, in V, using the given data below: (1)

Oxidised species	Reduced species	$E^\ominus$ (V)	Oxidised species	Reduced species	$E^\ominus$ (V)
$\text{Li}^+(\text{aq}) + \text{e}^-$	$\text{Li}(\text{s})$	-3.04	$\text{Cu}^+(\text{aq}) + \text{e}^-$	$\text{Cu}^*(\text{aq})$	+0.15
$\text{K}^+(\text{aq}) + \text{e}^-$	$\text{K}(\text{s})$	-2.93	$\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^-$	$\text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Ca}(\text{s})$	-2.87	$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Cu}(\text{s})$	+0.34
$\text{Na}^+(\text{aq}) + \text{e}^-$	$\text{Na}(\text{s})$	-2.71	$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	$2\text{OH}^-(\text{aq})$	+0.40
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Mg}(\text{s})$	-2.37	$\text{Cu}^+(\text{aq}) + \text{e}^-$	$\text{Cu}(\text{s})$	+0.52
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^-$	$\text{Al}(\text{s})$	-1.66	$\frac{1}{2}\text{I}_2(\text{s}) + \text{e}^-$	$\text{I}^-(\text{aq})$	+0.54
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Mn}(\text{s})$	-1.18	$\text{Fe}^{3+}(\text{aq}) + \text{e}^-$	$\text{Fe}^{2+}(\text{aq})$	+0.77
$\text{H}_2\text{O}(\text{l}) + \text{e}^-$	$\frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^-(\text{aq})$	-0.83	$\text{Ag}^+(\text{aq}) + \text{e}^-$	$\text{Ag}(\text{s})$	+0.80
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Zn}(\text{s})$	-0.76	$\frac{1}{2}\text{Br}_2(\text{l}) + \text{e}^-$	$\text{Br}^-(\text{aq})$	+1.09
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Fe}(\text{s})$	-0.45	$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$	$\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Ni}(\text{s})$	-0.26	$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^-$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.36
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Sn}(\text{s})$	-0.14	$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^-$	$\text{Cl}^-(\text{aq})$	+1.36
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Pb}(\text{s})$	-0.13	$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^-$	$\text{Mn}^{2+} + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\text{H}^+(\text{aq}) + \text{e}^-$	$\frac{1}{2}\text{H}_2(\text{g})$	0.00	$\frac{1}{2}\text{F}_2(\text{g}) + \text{e}^-$	$\text{F}^-(\text{aq})$	+2.87



**Question 3****[18]**

3.1 Calcium hydroxide is slightly soluble in water.

3.1.1. Write an equation to show the dissociation of calcium hydroxide,  $\text{Ca(OH)}_2(\text{s})$ , in aqueous solution. Include state symbols. (1)

3.1.2 Calculate the solubility, in  $\text{mol dm}^{-3}$ , of  $\text{Ca(OH)}_2$ .

[ $K_{\text{sp}}$ :  $\text{Ca(OH)}_2$ ,  $5.02 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9}$ ] (2)

3.1.3 Suggest how the solubility of  $\text{Ca(OH)}_2$  in aqueous NaOH compares to its solubility in water. Explain your reasoning. (1)

3.2 Silver sulfate,  $\text{Ag}_2\text{SO}_4$ , is sparingly soluble in water. The concentration of its saturated solution is  $2.5 \times 10^{-2} \text{ mol dm}^{-3}$  at 298 K.

3.2.1 Write an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{SO}_4$ , and state its units. (1)

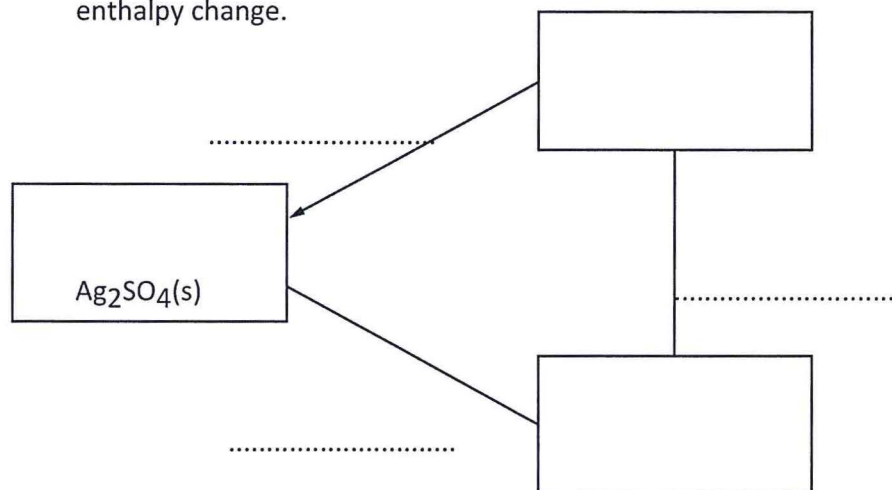
3.2.2 Calculate the value for  $K_{\text{sp}}(\text{Ag}_2\text{SO}_4)$  at 298 K. (1)

3.2.3 Using  $\text{Ag}_2\text{SO}_4$  as an example, redraw and complete the following Hess' Law energy cycle relating the: (5)

- lattice energy,  $\Delta H_{\text{latt}}^\circ$ ,
- enthalpy change of solution,  $\Delta H_{\text{sol}}^\circ$ , and
- enthalpy change of hydration,  $\Delta H_{\text{hyd}}^\circ$ .

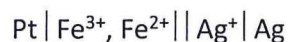
On your diagram:

- include the relevant species in the two empty boxes,
- label each enthalpy change with its appropriate symbol,
- complete the remaining two arrows showing the correct direction of enthalpy change.





3.3 Another electrochemical cell is set up as follows:



$\text{Ag}_2\text{SO}_4(\text{s})$  is formed at the Ag electrode

3.3.1 Use the Data in 2.6.4 to calculate the value of under standard conditions, stating which electrode is the positive one. (1)

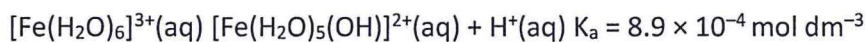
3.3.2 How would the actual  $E_{\text{cell}}$  of the above cell compare to the under standard conditions? Explain your answer. (1)

3.3.3 How would the  $E_{\text{cell}}$  of the above cell change, if at all, if a few  $\text{cm}^3$  of concentrated  $\text{Na}_2\text{SO}_4(\text{aq})$  were added to:

- the beaker containing  $\text{Fe}^{3+}(\text{aq}) + \text{Fe}^{2+}(\text{aq})$ ,
- the beaker containing  $\text{Ag}_2\text{SO}_4(\text{aq})$ ? (2)

3.3.4 Explain any changes in  $E_{\text{cell}}$  you have stated in 3.3.3. (1)

3.3.5 Solutions of iron(III) sulfate are acidic due to the following equilibrium.



Calculate the pH of a  $0.1 \text{ mol dm}^{-3}$  solution of iron(III) sulfate,  $\text{Fe}_2(\text{SO}_4)_3$ . (2)

**Question 4** **[10]**

4.1 Solution Y is hydrochloric acid,  $\text{HCl}(\text{aq})$ . Solution Z is aqueous 4-chlorobutanoic acid,  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$ . The  $\text{p}K_a$  of  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$  is 4.52. The pH of both solutions is 4.00.

4.1.1 Write an expression for the  $K_a$  of  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$ . (1)

4.1.2 Write a mathematical expression to describe the relationship between  $K_a$  and  $\text{p}K_a$ . (1)

4.1.3 Calculate  $[\text{H}^+]$  in solutions Y and Z. (1)

4.1.4 Calculate the ratio:

$$\frac{[\text{HCl}] \text{ dissolved in solution Y}}{[\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}] \text{ dissolved in solution Z}} \quad (2)$$



- 4.2 A buffer solution of pH 5.00 is produced by adding sodium propanoate to 5.00 g of propanoic acid in 100 cm<sup>3</sup> of distilled water. Calculate the mass of sodium propanoate that must be used to produce this buffer solution.  
The  $K_a$  of propanoic acid is  $1.35 \times 10^{-5} \text{ mol dm}^{-3}$ . (3)

[Mr: propanoic acid, 74.0; sodium propanoate, 96.0]

- 4.3 Some dilute sulfuric acid is mixed with a small sample of the buffer solution described in 4.2. The final pH of the mixture is close to 1.  
Explain this observation. (2)

**Question 5** [12]

Propene, C<sub>3</sub>H<sub>6</sub>, reacts with H<sub>2</sub>O in the presence of an acid catalyst to form an alcohol with Molecular formula C<sub>3</sub>H<sub>8</sub>O.

- 5.1 Name this type of reaction. (1)
- 5.2 Name the catalyst used and state the conditions needed for this reaction to occur. (2)
- 5.3 Redraw and Complete the table to show the numbers of sigma ( $\sigma$ ) bonds and pi ( $\pi$ ) bonds present in propene, C<sub>3</sub>H<sub>6</sub>, and C<sub>3</sub>H<sub>8</sub>O. (2)

	$\sigma$	$\pi$
C <sub>3</sub> H <sub>6</sub>		
C <sub>3</sub> H <sub>8</sub> O		

- 5.4 The reaction of propene, C<sub>3</sub>H<sub>6</sub>, with H<sub>2</sub>O occurs in a two-step mechanism.  
In step 1 C<sub>3</sub>H<sub>6</sub> reacts with the catalyst, H<sup>+</sup>, to form a carbocation.
- 5.4.1 Draw structures to identify the more stable and less stable carbocations which can form in step 1. Explain your answer. (3)
- 5.4.2 Name the major organic product formed from the reaction of propene, C<sub>3</sub>H<sub>6</sub>, with H<sub>2</sub>O. (1)
- 5.5 2-bromopropane reacts to form propene, hydrogen bromide and water under certain conditions.
- 5.5.1 Name this type of reaction. (1)
- 5.5.2 Describe the reagents and conditions needed to favour this reaction. (2)

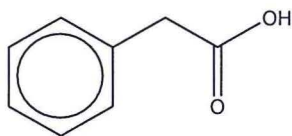




Question 6

[9]

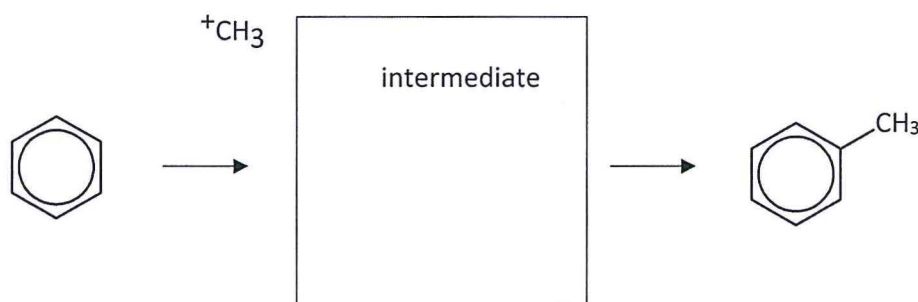
The structure of phenylethanoic acid is shown:



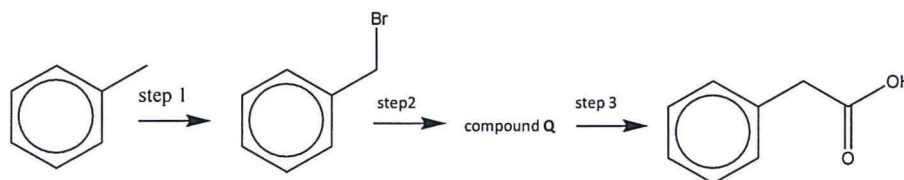
6.1 Phenylethanoic acid can be synthesised using benzene as the starting material. In the first stage of this synthesis, benzene reacts with chloromethane in the presence of an  $AlCl_3$  catalyst to form methylbenzene. Chloromethane reacts with  $AlCl_3$  to form two ions. One of these is the carbocation  $^+CH_3$ .

6.1.1 Write an equation for the reaction between chloromethane and  $AlCl_3$ . (1)

6.1.2 Redraw the diagrams below and draw the mechanism of the reaction between benzene and  $^+CH_3$ . Include all relevant curly arrows, charges and the structure of the intermediate. (3)



6.2 A three-step synthesis of phenylethanoic acid from methylbenzene is shown:



6.2.1 State reagents and conditions for step 1. (1)

6.2.2 Suggest the structure of compound Q. (1)

6.2.3 State reagents and conditions for steps 2 and 3. (2)

6.2.4 Draw the structure of an organic by-product that forms in step 1. (1)



**Question 7****[10]**

7.1 The reason for the wide variety of organic compounds is isomerism, either structural isomerism or stereoisomerism.

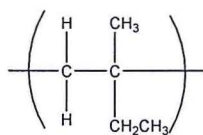
7.1.1 Explain the meaning of the term structural isomerism. (2)

7.1.2 Explain the meaning of the term stereoisomerism. (2)

7.2 Pent-1-ene,  $\text{CH}_2=\text{CH}(\text{CH}_2)_2\text{CH}_3$ , does not show stereoisomerism.

7.2.1 Give **two** reasons why pent-1-ene does not show stereoisomerism. (2)

7.2.2 A structural isomer of pent-1-ene is used as the monomer to form a polymer. The repeat unit of this polymer is shown:



Draw the displayed formula of the monomer used to make this polymer. Give the name of the monomer (2)

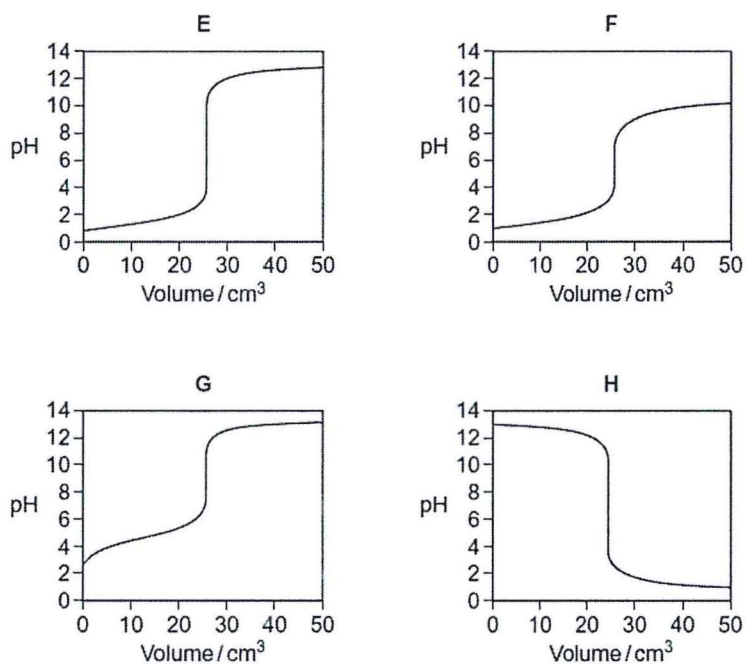
7.2.3 A different structural isomer of pent-1-ene shows geometrical isomerism. Draw the structure of one of the two geometrical isomers with the formula  $\text{C}_5\text{H}_{10}$ . Give the full name of this isomer. (2)



### Question 8

[6]

Titration curves, labelled E, F, G and H, for combinations of different aqueous solutions of acids and bases are shown in the diagrams below. All solutions have concentrations of  $0.1 \text{ mol dm}^{-3}$ .



- 8.1 From the curves E, F, G and H, choose the curve produced by the addition of:
- 8.1.1 sodium hydroxide to  $25 \text{ cm}^3$  of ethanoic acid (1)
- 8.1.2 ammonia to  $25 \text{ cm}^3$  hydrobromic acid (HBr) (1)
- 8.1.3 hydrochloric acid to  $25 \text{ cm}^3$  of potassium hydroxide (1)



8.2 The table below shows information about some acid-base indicators.

Indicator	pH range	Lower pH colour	Higher pH colour
pentamethoxy red	1.2–3.2	violet	colourless
naphthyl red	3.7–5.0	red	yellow
4-nitrophenol	5.6–7.0	colourless	yellow
cresol purple	7.6–9.2	yellow	purple

8.2.1 Which indicator in the **Table** could be used for the titration that produces curve **E** but **not** for the titration that produces curve **F**? (1)

8.2.2 Give the colour change at the end point of the titration that produces curve **H** when naphthyl red is used as the indicator. (1)

8.2.3 A beaker contains 25 cm<sup>3</sup> of a buffer solution at pH = 6.0  
Two drops of each of the four indicators in Table 2 are added to this solution.  
State the colour of the mixture of indicators in this buffer solution.  
You should assume that the indicators do not react with each other. (1)

**Question 9** [4]

9.1 Write the equations for the following decay processes:

Positron emission from silicon-26 (2)

9.2 The radioisotope fluorine-21 had an initial mass of 80 milligrams. 20 milligrams of sample remained unchanged after 8.32 s. What is the half life of F-21? (2)

**THE END**





# The Periodic Table of the Elements

	1	2											3	4	5	6	7	0	
																			(18)
																			4.0 He helium 2
																			20.2 Ne neon 10
																			39.9 Ar argon 18
																			83.8 Kr krypton 36
																			131.3 Xe xenon 54
																			[222] Rn radon 86
																			[294] Og oganeson 118

**Key**  
relative atomic mass  
**symbol**  
name  
atomic (proton) number

1.0
H
hydrogen 1

\* 58 – 71 Lanthanides

† 90 – 103 Actinides

140.1 <b>Ce</b> cerium 58	140.9 <b>Pr</b> praseodymium 59	144.2 <b>Nd</b> neodymium 60	[145] <b>Pm</b> promethium 61	150.4 <b>Sm</b> samarium 62	152.0 <b>Eu</b> europium 63	157.3 <b>Gd</b> gadolinium 64	158.9 <b>Tb</b> terbium 65	162.5 <b>Dy</b> dysprosium 66	164.9 <b>Ho</b> holmium 67	167.3 <b>Er</b> erbium 68	168.9 <b>Tm</b> thulium 69	173.0 <b>Yb</b> ytterbium 70	175.0 <b>Lu</b> lutetium 71
232.0 <b>Th</b> thorium 90	231.0 <b>Pa</b> protactinium 91	238.0 <b>U</b> uranium 92	[237] <b>Np</b> neptunium 93	[244] <b>Pu</b> plutonium 94	[243] <b>Am</b> americium 95	[247] <b>Cm</b> curium 96	[247] <b>Bk</b> berkelium 97	[251] <b>Cf</b> californium 98	[252] <b>Es</b> einsteinium 99	[257] <b>Fm</b> fermium 100	[258] <b>Md</b> mendelevium 101	[259] <b>No</b> nobelium 102	[262] <b>Lr</b> lawrencium 103

