**HWA CHONG INSTITUTION**
**C2 Preliminary Examination**
**Higher 2**

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|---|---|---|---|
| **CANDIDATE NAME** | | **CT GROUP** | 2 4 S |
| **CENTRE NUMBER** | S | **INDEX NUMBER** | |

# CHEMISTRY **9729/02**

Paper 2 Structured Questions **3 September 2025**

**2 hours**

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your **name**, **CT group, centre number** and **index number** on all the work you hand in.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE ON ANY BARCODES.

Answer all questions in the spaces provided in the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

| For Examiner's Use | |
|---|---|
| 1 | / 10 |
| 2 | / 18 |
| 3 | / 14 |
| 4 | / 14 |
| 5 | / 19 |
| Deductions (s.f.) | |
| Deductions (units) | |
| Deductions (structures) | |
| Total | / 75 |

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

**1 (a)** In Fig.1.1, sketch a graph to show the variation of ionic radius across Period 3. Explain the shape of your graph.

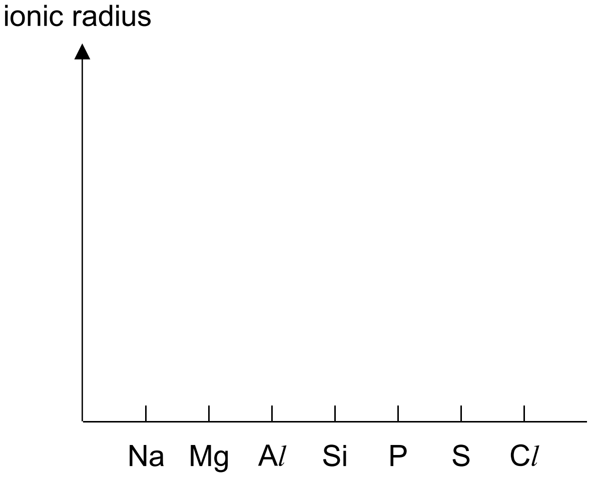


**Fig.1.1**

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**(b)** Write an equation for the reaction of $P_4O_{10}$ with water. State the pH of the resulting mixture.

equation ..........................................................................................................................

pH ................................................................................................................................ [1]

**(c)** Describe the acid-base behaviour of $Al_2O_3$ by reference to its reaction separately with sulfuric acid, $H_2SO_4$, and with sodium hydroxide, NaOH.

Write equations for any reactions described.

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**(d)** Aluminium chloride, $AlCl_3$, and beryllium chloride, $BeCl_2$, can act as Lewis acids.

**(i)** Explain what is meant by a Lewis acid.

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**(ii)** When heated with $AlCl_3$, bromine monochloride, $BrCl$, reacts with benzene in an electrophilic substitution reaction to produce bromobenzene.

Describe the mechanism for this reaction. In your answer, show how the electrophile is generated and include relevant lone pairs of electrons, dipoles and curly arrows.

[2]

**(iii)** In the solid form, $BeCl_2$ molecules polymerise to make long chains by forming co-ordinate (dative covalent) bonds.

Draw a diagram to represent part of a beryllium chloride polymer which contains at least three repeat units of $BeCl_2$. Label the co-ordinate bonds on your diagram.

The bonding in the beryllium chloride polymer is similar to that in $Al_2Cl_6$(g).

[1]

[Total: 10]

**2 (a)** In an experiment, 25.0 $cm^3$ of 0.500 mol $dm^{-3}$ LiOH(aq) was mixed rapidly in a polystyrene cup with 40.0 $cm^3$ of 0.500 mol $dm^{-3}$ HC*l*(aq), as shown in reaction 2.1.

reaction 2.1 $LiOH(aq) + HCl(aq) \rightarrow LiCl(aq) + H_2O(l)$ $\Delta H^{\ominus}_{neut}$

The initial temperature of each solution is 27.8 °C and the final temperature of the mixture is 30.5 °C.

**(i)** Define the term *standard enthalpy change of neutralisation*.

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**(ii)** Calculate the standard enthalpy change of neutralisation of lithium hydroxide, $\Delta H^{\ominus}_{neut}$, assuming that the solutions have a density of 1.00 g $cm^{-3}$ and a specific heat capacity of 4.18 J $g^{-1}$ °$C^{-1}$.

[2]

**(b)** Lithium hydroxide is used in air purification systems, particularly in enclosed environments like spacecrafts and submarines, to absorb carbon dioxide from the air. It achieves this by reacting with carbon dioxide to form lithium carbonate and water, as shown in reaction 2.2.

reaction 2.2 $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$ $\Delta H_2^\ominus$

**(i)** Construct an energy cycle to determine the standard enthalpy change of reaction 2.2, $\Delta H_2^\ominus$, using your answer in **(a)(ii)** and the data below.

$LiOH(s) \rightarrow Li^+(aq) + OH^-(aq)$ $\Delta H_3^\ominus = -21.0\ kJ\ mol^{-1}$

$Li_2CO_3(s) + 2HCl(aq) \rightarrow 2LiCl(aq) + CO_2(g) + H_2O(l)$ $\Delta H_4^\ominus = -29.0\ kJ\ mol^{-1}$

If you were unable to calculate a value for the standard enthalpy change of neutralisation of lithium hydroxide in **(a)(ii)**, you should use −48.2 kJ mol⁻¹. This is **not** the correct answer.

[3]

**(ii)** Deduce the sign of the entropy change for reaction 2.2, $\Delta S_2^\ominus$, and hence predict the effect of increasing temperature on the spontaneity of reaction 2.2, using your answer in **(b)(i)**.

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**(iii)** A spacecraft mission to the moon is planned with 8 crewmembers and supplied with 250 canisters of LiOH to purify the air via reaction 2.2. Each canister carries 5.2 kg of LiOH.

reaction 2.2 $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$ $\Delta H_2^\ominus$

Calculate the mass of $CO_2$ that would be exhaled, in terms of kg/CM-d (kilograms per crewmember per day), using the information below.

average volume of $CO_2$ exhaled per breath = 25 $cm^3$

number of breaths per minute = 15

density of $CO_2$ at room temperature = 1.98 g $dm^{-3}$

[2]

**(iv)** Determine the maximum number of days that this mission can last before all the LiOH in the canisters are used up. Give your answer as a whole number.

[2]

**(v)** Suggest one advantage of using lithium hydroxide for the space mission compared to other Group 1 hydroxides.

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**(c)** Unlike other Group 1 carbonates, lithium carbonate, $Li_2CO_3$, decomposes in a similar manner to magnesium carbonate.

**(i)** Write an equation, with state symbols, for the thermal decomposition of $Li_2CO_3$. Suggest a reason for the ease of decomposition of $Li_2CO_3$.

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**(ii)** The thermal decomposition temperatures of three carbonates are given in Table 2.1.

**Table 2.1**

| carbonate | decomposition temperature / °C |
|---|---|
| $MgCO_3$ | 350 |
| $CaCO_3$ | 635 |
| $Na_2CO_3$ | 851 |

Using data from the *Data Booklet* and Table 2.1, suggest a minimum temperature at which $Li_2CO_3$ will decompose, giving your reasoning.

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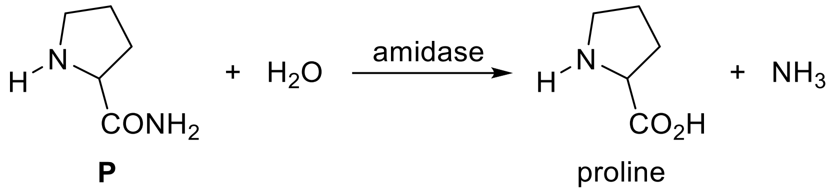
[Total: 18]

3 **(a)** An amide, **P**, can be hydrolysed by an enzyme, amidase, to form proline and ammonia.

reaction 3.1



**(i)** An optically inactive sample of **P** is used in the above reaction. State the maximum percentage of this sample that would be converted to proline by the enzyme amidase. Explain your reasoning.

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A series of experiments were carried out to study the kinetics of reaction 3.1. The initial rate of the reaction was measured for different initial concentrations of **P** at a constant temperature, while keeping the enzyme concentration fixed. The rate equation observed is in the form

$$\text{rate} = k[\mathbf{P}]^n$$

where n is the order of reaction with respect to [**P**] and $k$ is the observed rate constant.

The results of the experiments are shown in Table 3.1.

**Table 3.1**

| experiment | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| initial [**P**] / $10^{-3}$ mol dm$^{-3}$ | 0.50 | 1.00 | 2.00 | 4.00 | 8.00 | 16.00 |
| initial rate / $10^{-4}$ mol dm$^{-3}$ s$^{-1}$ | 1.25 | 2.50 | 5.00 | 7.00 | 8.00 | 8.00 |

**(ii)** Explain why the concentrations of the enzyme amidase and the reactant $H_2O$ do not appear in the rate equation.

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**(iii)** The order of reaction with respect to [**P**] may vary at lower and higher concentrations of **P**.

Using the data in Table 3.1, deduce the order of reaction with respect to [**P**], giving your reasoning.

- lower concentrations of **P**

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- higher concentrations of **P**

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**(iv)** Explain the relationship between the initial rate of the reaction and the concentration of **P** in this enzyme-catalysed reaction.

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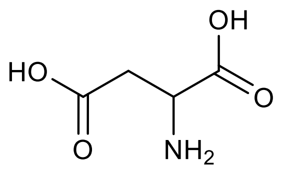
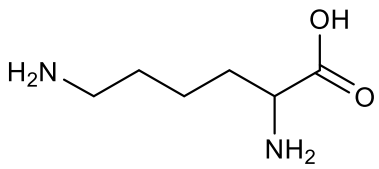
**(b)** The polypeptide chain of the enzyme amidase contains residues of two $\alpha$-amino acids, aspartic acid and lysine.




aspartic acid (asp)




lysine (lys)

**(i)** There are three p$K_a$ values associated with aspartic acid: 2.1, 3.7 and 9.8.

Draw the structures of the major species present in solutions of aspartic acid at

- pH 3 and
- pH 14.

| pH 3 | pH 14 |
|---|---|
| | |

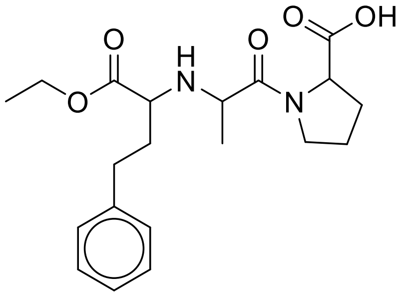
[2]

**(ii)** Aspartic acid and lysine can form a dipeptide named asp-lys, in which asp bears the free $NH_2$ end while lys bears the free $CO_2H$ end.

Draw the structure of the asp-lys dipeptide. The peptide bond formed should be shown displayed.

[1]

**(c)** Enalapril is a synthetic analog of proline used to treat hypertension.



enalapril

Draw the structures of the three organic products formed when enalapril is heated in excess dilute NaOH.

[3]

[Total: 14]

4 The mercury cell electrolysis process shown in Fig. 4.1 is an industrial method used primarily to produce $Cl_2$(g) and NaOH(aq) from brine, a concentrated solution of NaCl(aq). A pump circulates mercury liquid, Hg(l), between the primary and secondary chambers where different reactions take place.

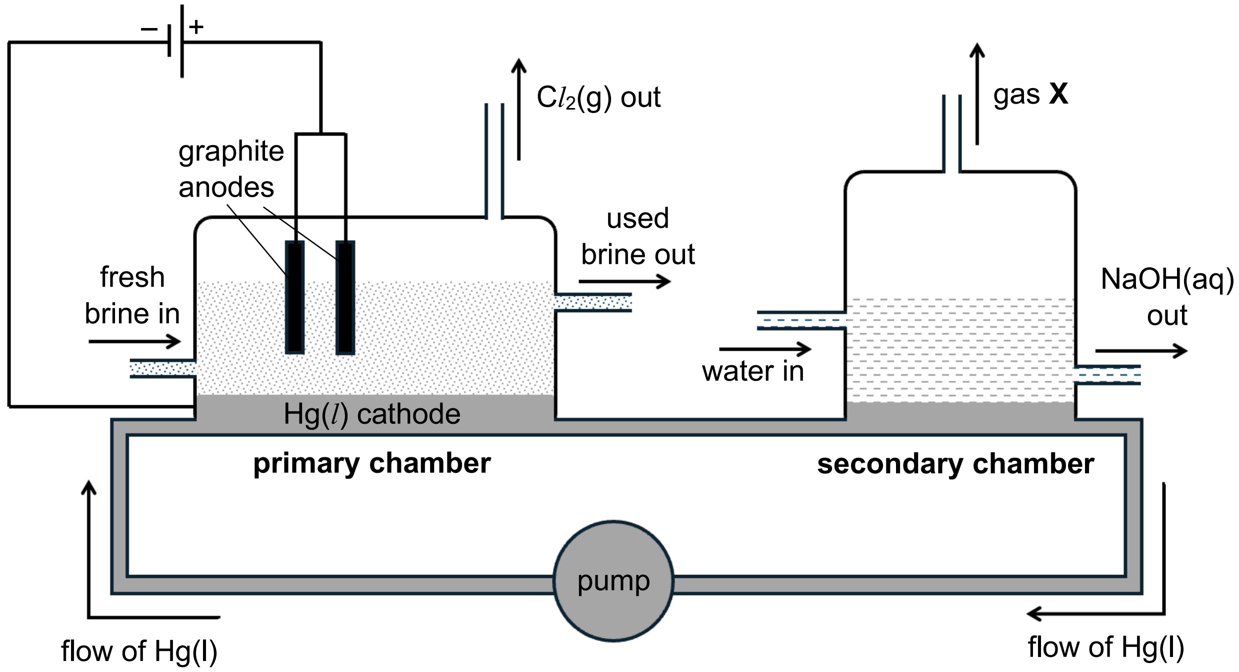



**Fig. 4.1**

The typical conditions under which the mercury cell is operated are summarised in Table 4.1.

**Table 4.1**

| | |
|---|---|
| temperature of mercury cell and its gaseous products | 70 °C |
| concentration of brine, NaCl(aq) | 5.0 mol dm$^{-3}$ |
| pressure of all gases | 1.0 bar |
| average operating current | 5000 A |
| coulombic efficiency | 88% |

**Primary chamber**

At the graphite anodes, $Cl^-$ ions are preferentially discharged to form $Cl_2$(g).

reaction at anodes: $2Cl^- \rightarrow Cl_2(g) + 2e^-$

At the Hg(l) cathode, $Na^+$ ions are discharged as Na atoms, which immediately dissolve in Hg to form a liquid mixture of Na and Hg known as a sodium amalgam, NaHg(l). The oxidation state of Na in NaHg is 0.

reaction at cathode: $Na^+(aq) + Hg(l) + e^- \rightarrow NaHg(l)$

Although a competing reaction is $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$, it is more feasible to reduce $Na^+$ due to the high stability of NaHg.

**Secondary chamber**

The NaHg(l) flows to a secondary chamber where it reacts with water to produce NaOH(aq) and gas **X.** This reaction regenerates Hg(l), which is cycled back by the pump into the primary chamber. Gas **X** is the third industrially useful product of the mercury cell electrolysis process.

**(a)** A key benefit of producing $Cl_2$ and NaOH in separate chambers is to prevent them from reacting with each other to produce NaC*l*, $NaClO_3$ and water, as shown in reaction 4.1.

reaction 4.1 $Cl_2$ + NaOH → NaC*l* + $NaClO_3$ + $H_2O$ (unbalanced)

**(i)** By considering electron transfer, state the type of reaction that chlorine undergoes in reaction 4.1.

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**(ii)** Hence, balance the equation for reaction 4.1.

....... $Cl_2$ + ....... NaOH → ....... NaC*l* + ....... $NaClO_3$ + ....... $H_2O$ [1]

**(b)** At the graphite anodes, a competing reaction is: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$.

**(i)** By quoting relevant $E^\ominus$ values from the *Data Booklet*, explain why $O_2$ will be produced at the anode instead of $Cl_2$ if dilute NaC*l*(aq) was electrolysed under standard conditions.

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**(ii)** Explain how using conditions stated in Table 4.1 allows for $Cl_2$ to be produced at the anodes of this mercury cell electrolysis process.

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**(c)** Coulombic efficiency measures the percentage of the total charge that is used to produce a desired product. A high coulombic efficiency indicates that minimal charge is wasted on producing unwanted side products.

$$\text{coulombic efficiency} = \frac{\text{actual charge used to produce } Cl_2(g)}{\text{total charge passed through mercury cell}} \times 100\%$$

Use relevant data from Table 4.1 to calculate the actual yield of $Cl_2$ gas in $m^3$ per hour. You may assume that $Cl_2$ gas behaves ideally.

[3]

**(d)** **(i)** Write an equation for the reaction that takes place in the secondary chamber and identify gas **X**.

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**(ii)** State an industrial use for gas **X**.

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**(e)** Studies into the high stability of sodium amalgam, NaHg(l), revealed the following characteristics about its chemical structure:

- Na atoms lose their valence electrons to form $Na^+$ ions.
- Some electron density is delocalised to form a sea of electrons.
- Some Hg atoms accept electron density to form Hg-rich polyanions like $Hg_4^{4-}$ and $Hg_2^{2-}$.

Table 4.2 shows the electronegativity values of the atoms in NaHg(l). The electronegativity of fluorine is listed as a reference.

**Table 4.2**

| atom | electronegativity / Pauling units |
|---|---|
| Na | 0.93 |
| Hg | 2.00 |
| F | 3.98 |

**(i)** Explain what is meant by the term *electronegativity*.

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**(ii)** Use the information given above to suggest two types of chemical bonds that are present in NaHg(l). Using the electronegativity values in Table 4.2, explain why each chemical bond is formed.

| chemical bond | explanation |
|---|---|
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5 (a) Describe and explain the trend in the thermal stability of the hydrogen halides HC*l*, HBr and HI. Include an equation for the thermal decomposition reaction in your answer.

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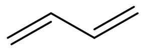
(b) Alkanes react with chlorine to form chloroalkanes and HC*l* as a by-product.

Draw the mechanism of the reaction between cyclopentane and chlorine in UV light to form chlorocyclopentane.

[3]

**(c)** Conjugated dienes contain C=C double bonds separated by exactly one C−C single bond. 1,3-butadiene is an example of a conjugated diene.



1,3-butadiene

Conjugated dienes exhibit chemical properties similar to alkenes but also undergo unique reactions.

When an equimolar ratio of 1,3-butadiene and HBr are reacted together, two different products can form via an electrophilic addition mechanism, as shown in Fig. 5.1.

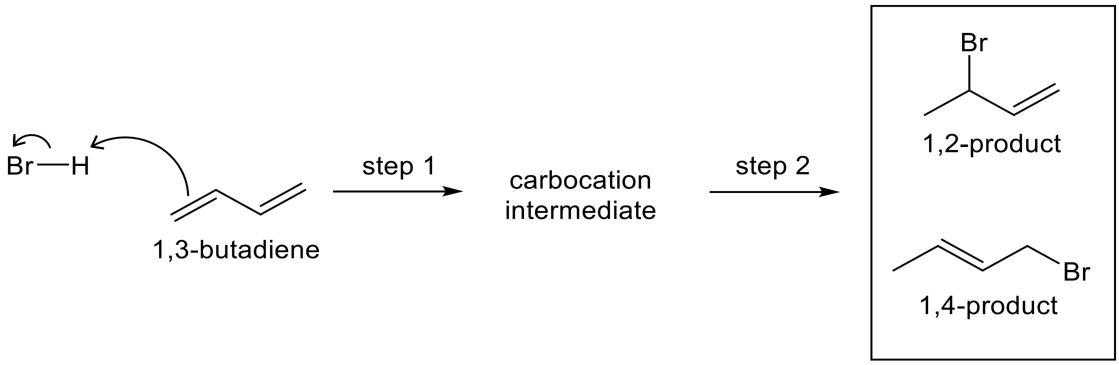



**Fig. 5.1**

**(i)** Draw the structure of the carbocation intermediate that forms **each** of the products shown in Fig. 5.1, and hence explain why the 1,4-product can be obtained from this reaction.

| carbocation structure that forms 1,2-product | carbocation structure that forms 1,4-product |
|---|---|
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**(ii)** The major product in the above reaction with HBr is the 1,2-product.

When IBr is used instead of HBr in the reaction, the same mechanism occurs. However, the 1,4-product becomes the major product.

Suggest a reason for this difference in product ratios.

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**(iii)** Table 5.1 shows the energies involved in the mechanism leading to the two products.

**Table 5.1**

| | |
|---|---|
| activation energy for step 2 to form 1,2-product, $E_{a2}(1,2)$ | 50 kJ mol$^{-1}$ |
| activation energy for step 2 to form 1,4-product, $E_{a2}(1,4)$ | 70 kJ mol$^{-1}$ |
| enthalpy change of reaction to form 1,2-product, $\Delta H_r^\ominus(1,2)$ | –100 kJ mol$^{-1}$ |
| enthalpy change of reaction to form 1,4-product, $\Delta H_r^\ominus(1,4)$ | –120 kJ mol$^{-1}$ |

Using the data in Table 5.1, complete the energy profile diagram for the two-step mechanism in Fig. 5.1, on the axes provided in Fig. 5.2. Show clearly the pathway to form **both** products. Include labels to show the activation energies, enthalpy changes and products clearly.

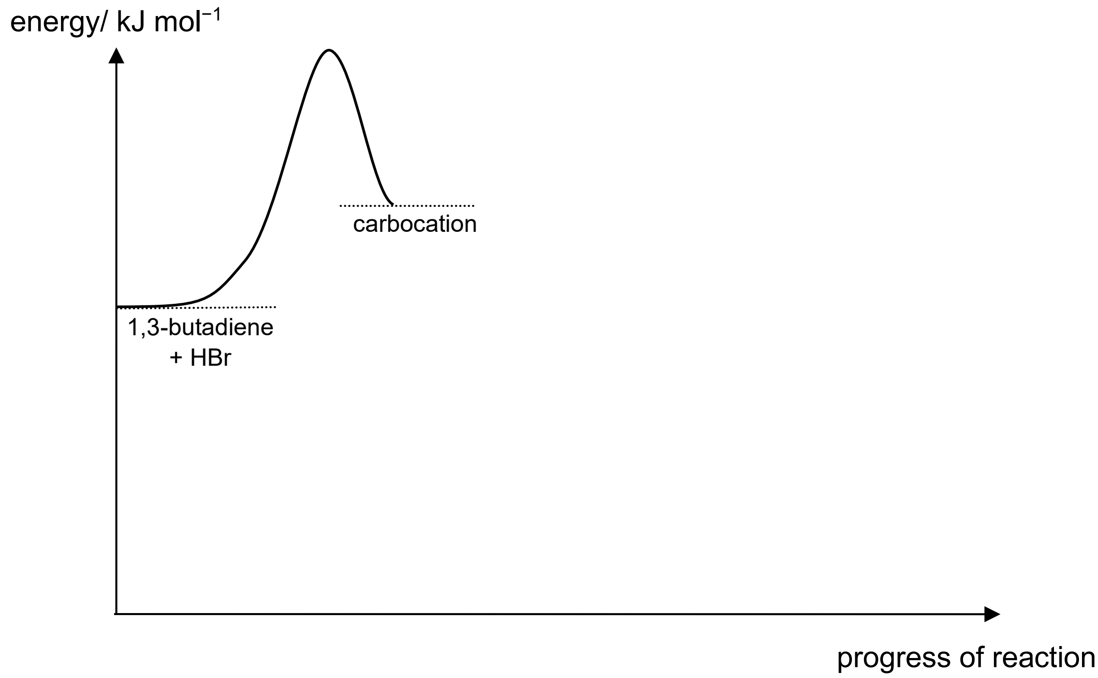


**Fig. 5.2**

[2]

**(iv)** The product ratios of a reversible reaction with the above energy profile can vary according to the temperature.

By considering the rates of reaction and enthalpy changes, use your answer in **(c)(iii)** to explain the following observations.

- At low temperature, the 1,2-product is the major product.

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- At high temperatures, the 1,4-product is the major product.

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**(d)** Sunscreens protect against harmful UV radiation using organic and inorganic filters. Organic filters are typically aromatic compounds with extended conjugated systems which enable them to absorb UV light. Inorganic filters are usually metal oxides.

Table 5.2 shows a list of sunscreen ingredients and their properties.

**Table 5.2**

| ingredient | type of filter | UV range (nm) | appearance at room temperature | opacity on skin | particle size (nm) |
|---|---|---|---|---|---|
| avobenzone | organic | 310 – 400 | colourless liquid | transparent | – |
| octocrylene | organic | 280 – 320 | colourless liquid | transparent | – |
| ZnO | inorganic | 280 – 370 | white solid | nearly transparent | 20 – 50 |
| $TiO_2$ | inorganic | 290 – 340 | white solid | nearly transparent | 15 – 30 |

1 nm = $1 \times 10^{-9}$ m

**(i)** By considering their electronic configurations, explain why ZnO and $TiO_2$ appear white at room temperature.

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Table 5.3 shows the active ingredients in three sunscreen formulations.

**Table 5.3**

| formulation | active ingredients |
|---|---|
| **X** | 5% avobenzone + 3% octocrylene |
| **Y** | 10% ZnO |
| **Z** | 7% $TiO_2$ |

**(ii)** A broad-spectrum sunscreen protection refers to protection against two forms of solar radiation – UVA and UVB, with ranges of 315 – 400 nm and 280 – 315 nm respectively.

Using data from Tables 5.2 and 5.3, suggest and explain which formulation is the most effective as a broad-spectrum sunscreen.

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**(e)** Octocrylene degrades via a first-order reaction with a half-life of 12.8 hours when applied to skin exposed to sunlight.

**(i)** Explain what is meant by the *half-life* of a reaction.

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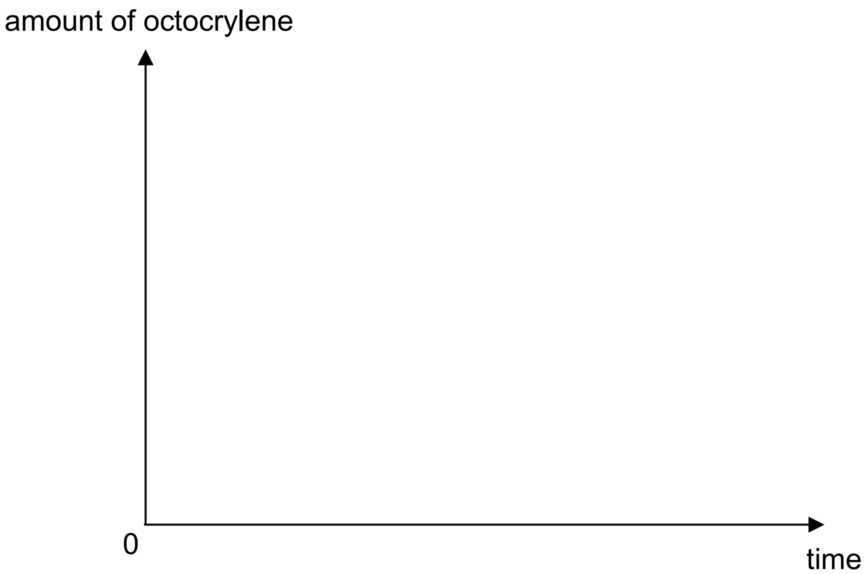
**(ii)** Calculate how long it would take for octocrylene to fall to $\frac{1}{8}$ of its initial value.

[1]

**(iii)** Sketch a graph to show how the amount of octocrylene decreases with time after application on the skin. Indicate two half-lives on your sketch, labelling your sketch clearly.

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