



Oxford Cambridge and RSA

Monday 20 June 2022 – Morning

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Time allowed: 2 hours 15 minutes



You must have:

- a clean copy of the Advance Notice Article (inside this document)
- the Data Sheet for Chemistry B

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE

- Read each question carefully before you start your answer.

Answer **all** the questions.

- 1 Portland cement is a powder that 'sets' to a strong solid when water is added. The cement is usually mixed with gravel so that it sets to make concrete.

The typical ingredients of Portland cement are shown in the table.

Ingredients (solids)	% by mass
CaO	61 – 67
SiO ₂	19 – 23
Al ₂ O ₃	2.5 – 6
Fe ₂ O ₃	0 – 6
SO ₃	1.5 – 4.5

- (a) Give the systematic name for Fe₂O₃.

iron(III) oxide..... [1]

- (b) (i) A hazard warning for Portland cement states that it is alkaline.

One of the ingredients in the table reacts with water to form an alkaline solution.

Write an equation for the reaction of this ingredient with water including any ions that are formed.



[2]

- (ii) When Portland cement sets, the calcium oxide absorbs carbon dioxide from the air.

Suggest an equation for the reaction that occurs.



[1]

- (c) One way of testing for the presence of calcium in the cement would be a flame test, though any iron present would interfere.

- (i) What is the flame colour of calcium?

brick red..... [1]

- (ii) The flame colour is caused by bright lines in the atomic emission spectrum of calcium.

Explain how these lines are formed.

Electrons absorb energy (heat from the flame) and are excited (raised) to higher energy levels. They then drop back to lower energy levels, emitting photons of light of a specific frequency ($\Delta E = h\nu$), which gives the bright lines. [2]

- (iii) Calculate the frequency of a line of wavelength 6.16×10^{-7} m.

$$c = f\lambda, \text{ so } f = c \div \lambda$$

$$f = 3.00 \times 10^8 \div 6.16 \times 10^{-7} = 4.87 \times 10^{14} \text{ Hz}$$

frequency = 4.87×10^{14} Hz [2]

- (d) Fe_2O_3 and CaO are present in Portland cement.

- (i) In which 'blocks' of the periodic table are these elements found?

Ca *s*

Fe *d* [1]

- (ii) The electron configuration of a calcium **ion** is $1s^2 2s^2 2p^6 3s^2 3p^6$.

How does the electron configuration of the **cation** in Fe_2O_3 differ from this?

Fe^{3+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$; it has five extra electrons, in the 3d subshell ($[\text{Ar}]3d^5$). [1]

- (iii) Explain why iron can form two stable cations.

Iron is a transition metal; more than one d configuration ($3d^6$ in Fe^{2+} , $3d^5$ in Fe^{3+}) is stable, so it forms ions with different oxidation states. [1]

- (e) Fe_2O_3 is soluble in concentrated hydrochloric acid.

Excess sodium hydroxide is added to this solution.

Name the precipitate formed and describe its colour.

name: *iron(III) hydroxide, $\text{Fe}(\text{OH})_3$*

colour: *orange-brown precipitate* [1]

- (f) (i) A student has a solution containing $\text{Fe}^{3+}(\text{aq})$ and reads that it will react with iodide ions to form iodine. The iodine can then be titrated with sodium thiosulfate.

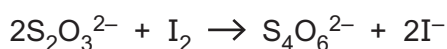
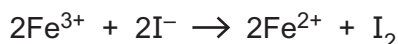
Describe a method to measure the volume of sodium thiosulfate solution required to react with the iodine from 25 cm^3 of $\text{Fe}^{3+}(\text{aq})$.

Use a pipette to transfer 25.0 cm^3 of the $\text{Fe}^{3+}(\text{aq})$ into a conical flask.
Add excess potassium iodide solution so all the Fe^{3+} reacts, forming
iodine.
Fill a burette with the sodium thiosulfate solution and titrate, swirling,
until the brown colour fades to pale yellow.
Add starch indicator near the end point (blue-black), then add thiosulfate
dropwise until the blue-black colour just disappears.
Repeat until concordant titres (within 0.10 cm^3) are obtained and find
the mean titre.

[5]

- (ii) The student finds that 25.0 cm^3 of $\text{Fe}^{3+}(\text{aq})$ requires 3.2 cm^3 of 0.510 mol dm^{-3} sodium thiosulfate.

Calculate the concentration of the $\text{Fe}^{3+}(\text{aq})$.



Give your answer to an **appropriate** number of significant figures.

$$n(\text{S}_2\text{O}_3^{2-}) = 3.2 \times 0.510 \div 1000 = 1.63 \times 10^{-3} \text{ mol}$$

$$n(\text{I}_2) = 1.63 \times 10^{-3} \div 2 = 8.16 \times 10^{-4} \text{ mol}$$

$$n(\text{Fe}^{3+}) = 2 \times n(\text{I}_2) = 1.63 \times 10^{-3} \text{ mol in } 25.0\text{ cm}^3$$

$$[\text{Fe}^{3+}] = 1.63 \times 10^{-3} \times 1000 \div 25.0 = 0.0653 \text{ mol dm}^{-3}$$

$$= 0.065 \text{ mol dm}^{-3} \text{ (2 s.f., as the titre } 3.2\text{ cm}^3 \text{ has 2 s.f.)}$$

$$[\text{Fe}^{3+}] = \dots\dots\dots 0.065 \dots\dots\dots \text{ mol dm}^{-3} \text{ [3]}$$

- (iii) The student decides to repeat the experiment using $0.0510 \text{ mol dm}^{-3}$ sodium thiosulfate.

Suggest why the student does this.

With the more dilute thiosulfate the titre is ten times larger (about 32 cm^3).
So the percentage measurement uncertainty (% error) in the titre is smaller, and the answer can be quoted to 3 significant figures. [2]

- (g) Iron is formed in stars by fusion reactions.

Complete the nuclear equation for one such reaction.



- (h) The table shows the stable isotopes of iron and their abundances.

Mass number	Abundance / %
54	5.85
56	91.75
57	2.12
58	0.28

- (i) What is meant by the term **mass number**?

The total number of protons and neutrons in the nucleus of an atom. [1]

- (ii) Explain, without doing a calculation, how this data shows that the relative atomic mass of iron is below 56.

The abundance of the isotope below 56 (5.85% for ${}^{54}\text{Fe}$) is bigger than the total abundance of the isotopes above 56 ($2.12 + 0.28 = 2.40\%$). [1]

2 'Polybutene' is used in lip gloss.

The monomers for polybutene are the three isomers of butene, which are 2-methylpropene, but-2-ene and isomer **A**.

(a) Draw the **skeletal** formula of isomer **A** and name it.

skeletal formula:



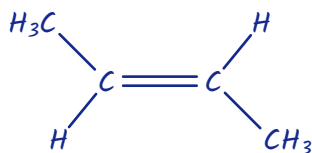
name: *but-1-ene* [1]

(b) Give the number of π bonds and σ bonds in but-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$.

π bonds *1* σ bonds *11* [1]

(c) But-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$, exists as *E* and *Z* isomers.

(i) Draw the structure of the *E* isomer of but-2-ene.



[1]

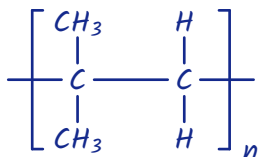
(ii) Does 2-methylpropene, $(\text{CH}_3)_2\text{C}=\text{CH}_2$, have *E* and *Z* isomers?

Explain your answer.

No, because one of the C atoms in the $\text{C}=\text{C}$ has two identical groups.....

(two methyl groups) attached to it...... [1]

(d) Draw the repeating unit of the polymer of 2-methylpropene, $(\text{CH}_3)_2\text{C}=\text{CH}_2$.



[1]

(e) The presence of the three isomers as monomers in 'polybutene' means that different side-chains are present that do not allow the polymer chains to get close together. This causes the polymer to be a liquid suitable for lip gloss.

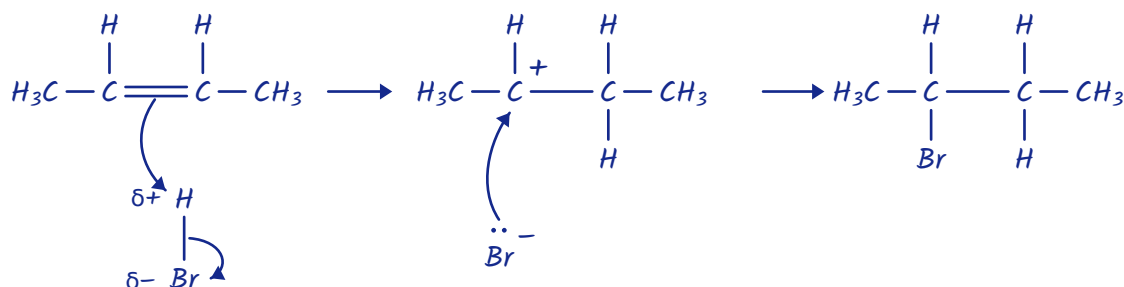
Name the intermolecular bonds that hold the chains together in polybutene.

instantaneous dipole-induced dipole bonds (id-id)..... [1]

- (f) But-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$, reacts with hydrogen bromide.

Draw the mechanism for this reaction.

Show curly arrows, full charges and the product.



[3]

- (g) But-2-ene reacts with hydrogen to form butane.

Name a catalyst and the corresponding conditions for this reaction.

catalyst: nickel

conditions: heat (about 150 °C) and pressure (about 3 atm) [1]

- (h) But-2-ene is formed industrially by cracking alkanes from crude oil.

- (i) Complete the equation for a cracking reaction.

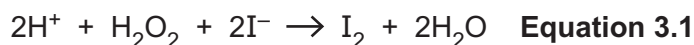


- (ii) Cracking is an example of heterogeneous catalysis.

Name the **first** step in the mechanism of heterogeneous catalysis.

adsorption (of the reactants onto the catalyst surface) [1]

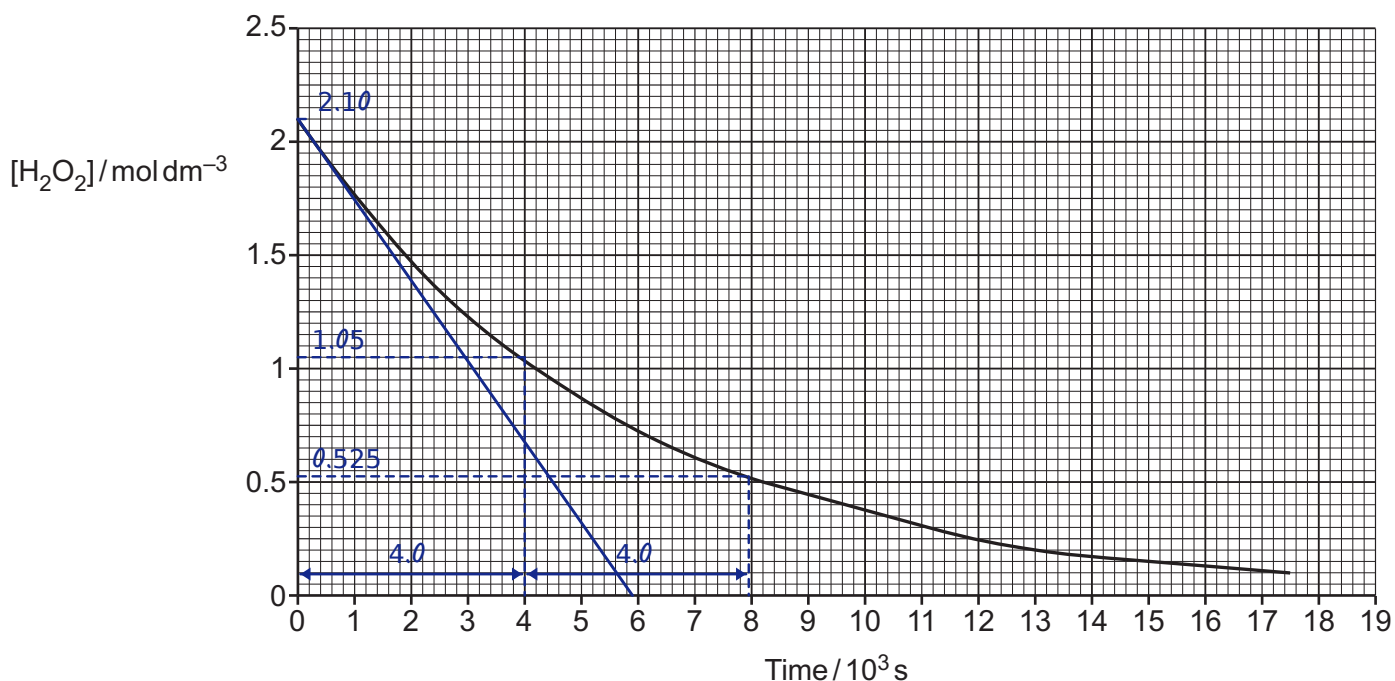
- 3 Some students read about the reaction between hydrogen peroxide and iodide ions as shown in equation 3.1.



- (a) The students find the results of an experiment which measures the concentration of hydrogen peroxide at various times.

Large excesses of acid and iodide ions are present.

The students plot a graph of these results as shown below.



- (i) Use the graph to measure two half-lives to show that the kinetics are first order.

Show your working on the graph.

first half-life = $4.0 \times 10^3 \text{ s}$ ($2.10 \rightarrow 1.05 \text{ mol dm}^{-3}$)

second half-life = $4.0 \times 10^3 \text{ s}$ ($1.05 \rightarrow 0.525$): constant, so first order [3]

- (ii) Use the graph to measure the initial rate of the reaction in $\text{mol dm}^{-3} \text{ s}^{-1}$.

initial rate = $3.6 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$ [1]

Tangent drawn at $t = 0$: gradient = $-2.10 \div (5.9 \times 10^3) = -3.6 \times 10^{-4}$

$\text{mol dm}^{-3} \text{ s}^{-1}$, so initial rate = $3.6 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$

- (iii) The graph shows that the reaction in **equation 3.1** is first order with respect to hydrogen peroxide.

Explain why the orders with respect to the other reagents cannot be determined from this experiment.

Acid and iodide ions are present in large excess, so their concentrations hardly change during the reaction.
Only $[H_2O_2]$ changes (is varied), so the effect of $[H^+]$ and $[I^-]$ on the rate cannot be seen. [2]

- (b) The students then set up some experiments to find the orders of reaction with respect to iodide and hydrogen ions.

At the starting time they mix the hydrogen peroxide, acid and iodide ions together with a fixed volume of sodium thiosulfate and starch solutions.

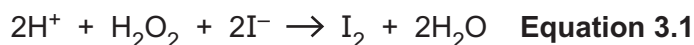
They measure the time for the colourless solutions suddenly to go dark blue as iodine is formed.

- (i) Suggest why the tubes go dark blue after a period of time rather than gradually from the start.

The iodine formed reacts immediately with the thiosulfate ions ($I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$), so no free iodine is present at first.
Once the fixed amount of thiosulfate is used up, free iodine remains and forms a dark blue-black colour with the starch.
 [2]

- (ii) How can the relative rates of reaction be found from the students' results?

Relative rate is proportional to $1/\text{time}$ ($1/t$) for the blue colour to appear.
 [1]



(c)* The students' results are shown below.

Use these results and information from earlier in the question to work out the rate equation for the reaction, explaining your reasoning.

Calculate the rate constant, k , and suggest a possible mechanism for the reaction.

Experiment	$[\text{H}_2\text{O}_2]$ $/\text{mol dm}^{-3}$	$[\text{I}^-]$ $/\text{mol dm}^{-3}$	$[\text{H}^+]$ $/\text{mol dm}^{-3}$	Initial rate of formation of I_2 $/\text{mol dm}^{-3} \text{s}^{-1}$
1	0.030	0.010	0.10	5.25×10^{-6}
2	0.030	0.020	0.10	1.05×10^{-5}
3	0.030	0.020	0.20	1.05×10^{-5}

From part (a), the reaction is first order with respect to H_2O_2 .

Experiments 1 and 2: $[\text{I}^-]$ doubles (0.010 to 0.020) with $[\text{H}^+]$ constant, and the rate doubles (5.25×10^{-6} to 1.05×10^{-5}), so it is first order with respect to I^- .

Experiments 2 and 3: $[\text{H}^+]$ doubles (0.10 to 0.20) but the rate stays the same (1.05×10^{-5}), so it is zero order with respect to H^+ .

Rate equation: $\text{rate} = k[\text{H}_2\text{O}_2][\text{I}^-]$

$k = \text{rate} \div ([\text{H}_2\text{O}_2][\text{I}^-]) = 5.25 \times 10^{-6} \div (0.030 \times 0.010) = 1.75 \times 10^{-2} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$

So the slow (rate-determining) step involves one H_2O_2 and one I^- but no H^+ ; H^+ reacts in a later fast step:

$\text{H}_2\text{O}_2 + \text{I}^- \rightarrow \text{H}_2\text{O} + \text{IO}^-$ (slow, rate-determining)

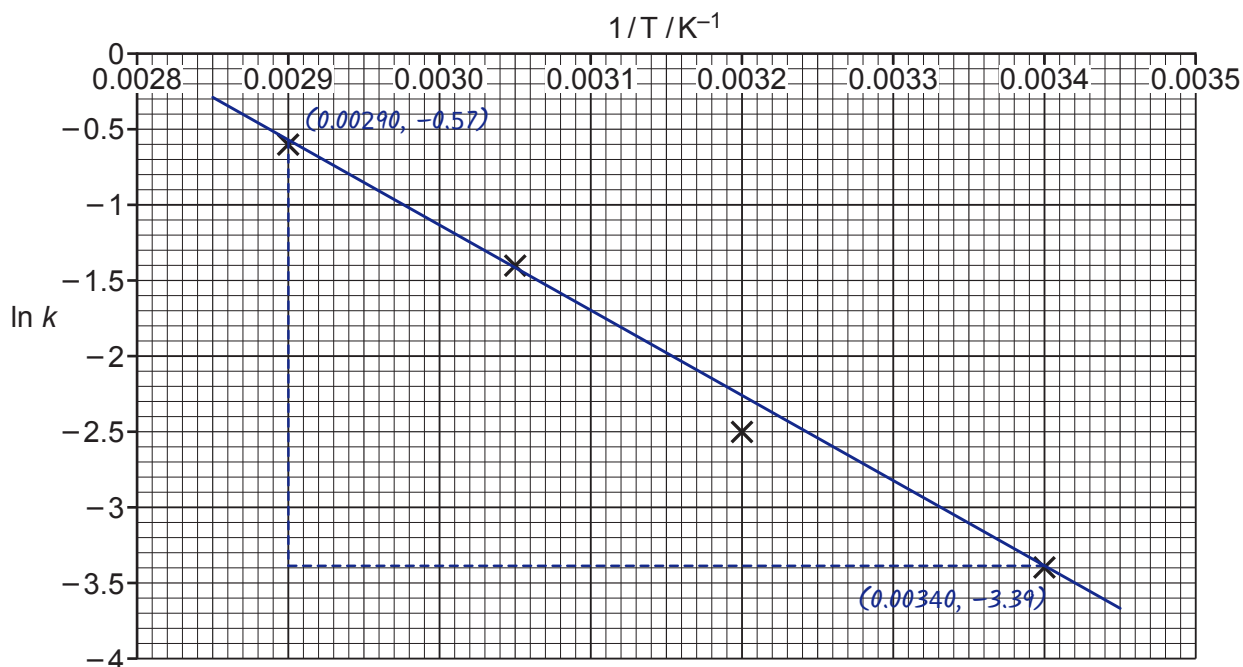
$\text{H}^+ + \text{IO}^- \rightarrow \text{HIO}$ (fast)

$\text{HIO} + \text{H}^+ + \text{I}^- \rightarrow \text{I}_2 + \text{H}_2\text{O}$ (fast)

These steps add up to the overall equation 3.1. [6]

Additional answer space if required

- (d) The students find data for the variation of the rate constant, k , with temperature. From their data they plot the graph below.



Use the graph to calculate E_a in kJ mol^{-1} for the reaction in **equation 3.1**.

$$\ln k = -E_a/RT + \ln A, \text{ so gradient} = -E_a/R$$

$$\text{gradient} = (-3.39 - (-0.57)) \div (0.00340 - 0.00290) = -2.82 \div 0.00050 = -5640 \text{ K}$$

$$E_a = -\text{gradient} \times R = 5640 \times 8.314 = 46\,900 \text{ J mol}^{-1}$$

$$E_a = 46\,900 \div 1000 = 46.9 \text{ kJ mol}^{-1}$$

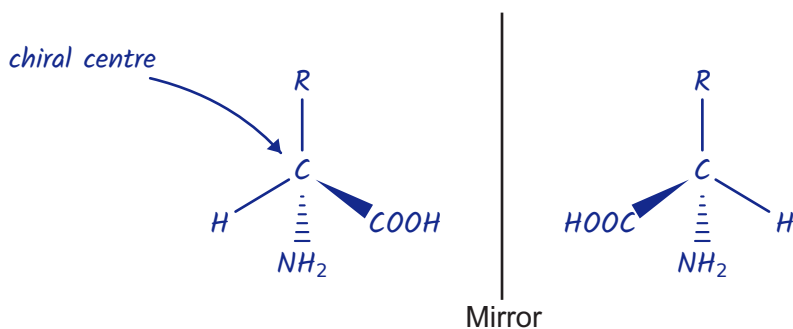
$$E_a = \dots\dots\dots +46.9 \dots\dots\dots \text{ kJ mol}^{-1} \text{ [4]}$$

- 4 Chymotrypsin is an enzyme present in the small intestine.

One of the amino acids in chymotrypsin is serine, which can be represented as HOOCCHRNH_2 .

- (a) (i) A molecule of serine has a chiral centre and two enantiomers.

Draw and label **two** serine molecules below to illustrate the meaning of the terms **chiral centre** and **enantiomer**.



The chiral centre is a C atom with 4 different groups (R, H, COOH, NH₂).

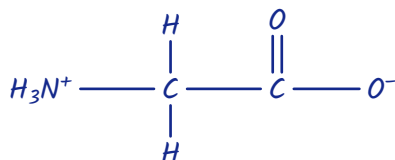
Enantiomers: the two molecules are non-superimposable mirror images.

[3]

- (ii) Glycine $\text{HOOCCH}_2\text{NH}_2$ is another amino acid.

In solution, glycine exists as a zwitterion.

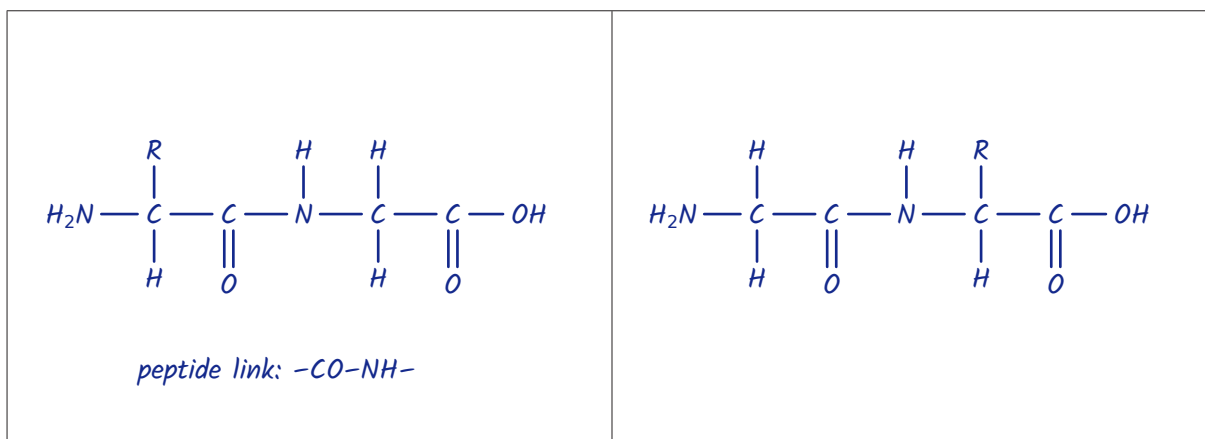
Draw the structure of this zwitterion.



[1]

- (b) Serine reacts with glycine to form two dipeptides.

- (i) In the boxes below, draw the structural formulae for the two dipeptides.



[2]

- (ii) Explain, with a reason, whether the reaction to form the dipeptides is condensation or addition.

*..Condensation, because a molecule of water is formed (eliminated) when.....
 ..the peptide bond forms..... [1]*

- (c) Chymotrypsin is a protein with a definite amino acid sequence and parts that have an α -helical structure.

- (i) What name is given to the amino acid sequence of a protein?

..primary..structure..... [1]

- (ii) What name is given to the α -helical structure and how is it held together?

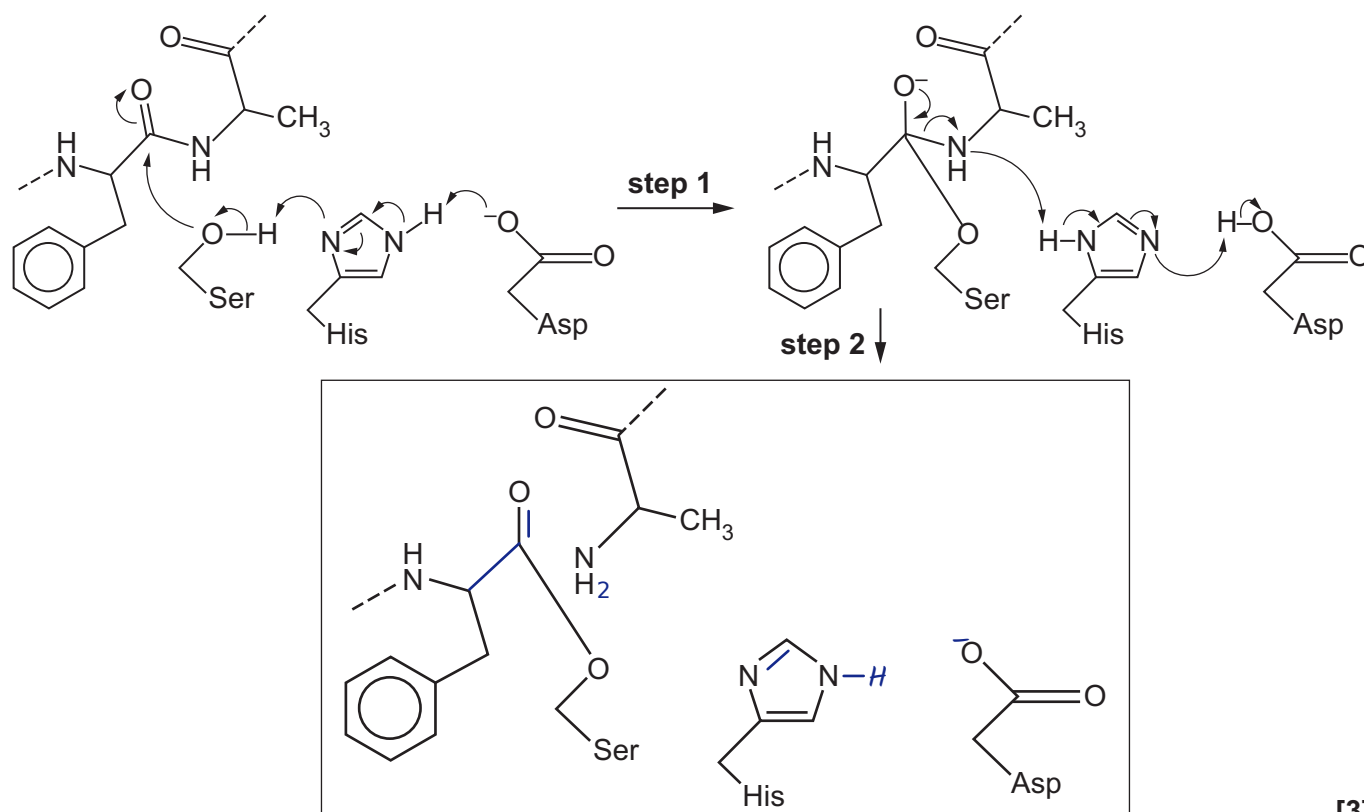
*..It is the secondary structure.....
 ..It is held together by hydrogen bonds between the $C=O$ of one peptide.....
 ..group and the $N-H$ of another further along the chain..... [2]*

- (d) Chymotrypsin catalyses the hydrolysis of proteins in the small intestine.

The active site of chymotrypsin consists of the amino acids serine, histidine and aspartic acid. These occur on different parts of the chain that are brought together by the folding of the structure.

The start of the hydrolysis mechanism is shown below. The protein being hydrolysed is at the top left.

Complete the diagram in the box below to show the results of the electron movements in step 2.

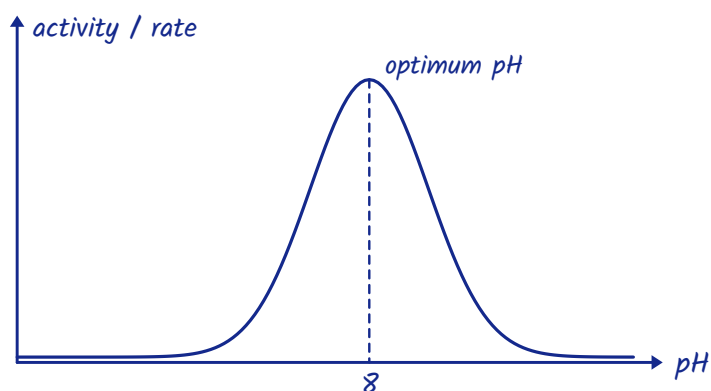


- (e) (i) Explain why warming a solution of chymotrypsin will destroy its activity as an enzyme.

Warming gives the molecules more energy, so the hydrogen bonds (and other weak bonds) holding the tertiary structure are broken. The active site changes shape (the enzyme is denatured), so the substrate no longer fits. [2]

- (ii) Chymotrypsin has an optimum pH = 8.

Draw a sketch to suggest the shape of the graph of chymotrypsin activity against pH.



Explain the shape of your graph.

Activity is highest at pH 8; at other pH values the active site changes shape (denatures), so activity falls. [3]

- (iii) A student says that the rate of an enzyme reaction is proportional to the substrate concentration.

Comment on the student's statement, correcting any errors.

The statement is only correct at low (initial) substrate concentrations; here the reaction is first order with respect to the substrate, so rate is proportional to [substrate]. At higher [substrate] all the active sites are occupied, so the rate levels off and becomes zero order; the rate no longer depends on [substrate]. [2]

- 5 This question concerns the Advanced Notice Article 'Fluoride compounds in dental hygiene' that is included as an insert with this paper.

(a) Hydrofluoric acid (HF) is described in the article as 'moderately strong' with a pK_a of 3.14.

(i) Write the expression for K_a for HF and give its units.

$$K_a = \frac{[H^+][F^-]}{[HF]}$$

units mol dm^{-3} [2]

(ii) Calculate the $\frac{[F^-]}{[HF]}$ ratio in hydrofluoric acid under the acidic conditions in plaque at pH 5.0.

$$K_a = 10^{-3.14} = 7.24 \times 10^{-4} \text{ mol dm}^{-3}$$

$$[H^+] = 10^{-5.0} = 1.0 \times 10^{-5} \text{ mol dm}^{-3}$$

$$[F^-]/[HF] = K_a \div [H^+] = 7.24 \times 10^{-4} \div 1.0 \times 10^{-5} = 72.4$$

$$\frac{[F^-]}{[HF]} = \dots\dots\dots 72.4 \dots\dots\dots [3]$$

(b) The HPO_4^{2-} ion is mentioned in the article.

Write the formula of the conjugate base of the HPO_4^{2-} ion and explain your answer.

PO_4^{3-}

A conjugate base forms when an acid loses a proton (H^+): $\text{HPO}_4^{2-} \rightarrow \text{PO}_4^{3-} +$

H^+ , so PO_4^{3-} accepts H^+ to re-form HPO_4^{2-} [2]

(c) SnF_2 is said in the article to hydrolyse at 'higher pH'.

Suggest an equation for the reaction between SnF_2 and hydroxide ions.



(d) Name the shape around the N atom in the $-\text{NH}_3^+$ group in dectafur.

tetrahedral [1]

- (e) (i) Explain the relationship between the ion product, IP, and the solubility product, K_{sp} , for an ionic substance.

K_{sp} is the product of the ion concentrations, $[Ca^{2+}][F^-]^2$, in a saturated solution (at equilibrium).
 IP is the same product for any concentrations: if $IP > K_{sp}$ the solution is supersaturated and a precipitate can form; if $IP < K_{sp}$ no precipitate forms. [2]

- (ii) Calculate the supersaturation of calcium fluoride in saliva after brushing.

Give your answer to the **nearest whole number**.

$$IP = [Ca^{2+}][F^-]^2 = 1.43 \times 10^{-3} \times (7.9 \times 10^{-3})^2 = 8.92 \times 10^{-8}$$

$$IP \div K_{sp} = 8.92 \times 10^{-8} \div 3.9 \times 10^{-11} = 2.29 \times 10^3$$

$$CaF_2 \text{ gives 3 ions, so supersaturation} = \text{cube root of } 2.29 \times 10^3 = 13.2$$

supersaturation = 13 [3]

- (f) Calculate the ppm by mass of fluorine in pure fluoroapatite, $Ca_5(PO_4)_3F$.

$$M_r \text{ of } Ca_5(PO_4)_3F = 5(40.1) + 3(31.0) + 12(16.0) + 19.0 = 504.5$$

$$\text{mass fraction of F} = 19.0 \div 504.5 = 0.0377$$

$$\text{ppm} = (19.0 \div 504.5) \times 10^6 = 3.77 \times 10^4$$

ppm by mass = 3.77×10^4 [2]

- (g)* Use information from the article to describe the chemistry of how fluoride improves dental health and to explain why this is **not** because of the formation of a protective or a hard layer.

Tooth enamel is hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$. The danger is attack by acids

(from bacteria in plaque), which dissolve it: $\text{Ca}_5(\text{PO}_4)_3\text{OH} + 4\text{H}^+ \rightarrow 5\text{Ca}^{2+} +$

$3\text{HPO}_4^{2-} + \text{H}_2\text{O}$.

Fluoride improves dental health by encouraging remineralisation, which is the

deposition of calcium phosphate back onto the enamel. With F^- present,

fluoroapatite precipitates: $5\text{Ca}^{2+} + 3\text{PO}_4^{3-} + \text{F}^- \rightarrow \text{Ca}_5(\text{PO}_4)_3\text{F}$.

This happens because fluoroapatite has the highest supersaturation in saliva

(212), so it is the most likely solid to precipitate. The F^- acts like a

catalyst, speeding up remineralisation.

This is not because a protective layer forms; the fluoride compounds that

form, calcium fluoride and fluoroapatite, are both soluble in acid, so they

cannot protect the tooth from acid attack.

It is not because a hard layer forms either: fluoroapatite is no harder than

hydroxyapatite, as the comparison with sharks' teeth (made of fluoroapatite)

shows.

[6]

Additional answer space if required

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END OF QUESTION PAPER

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