



Oxford Cambridge and RSA

Monday 16 June 2025 – Morning

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

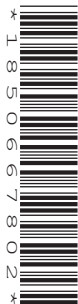
Time allowed: 2 hours 15 minutes

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)

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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 page 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.

1 This question is about reactions of haloalkanes.

(a) CH_3Cl is made by plants that grow on marshes.

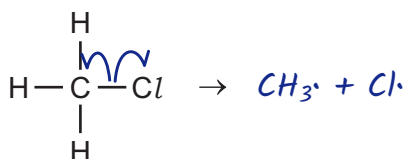
If CH_3Cl reaches the stratosphere, electromagnetic radiation causes it to undergo homolytic fission forming chlorine radicals.

(i) Give the systematic name of CH_3Cl .

Chloromethane [1]

(ii) Draw 'half curly arrows' to show the mechanism of the homolytic fission of CH_3Cl .

Show the products of the reaction.



[2]

(iii) Which **type** of electromagnetic radiation causes this homolytic fission to occur in the stratosphere?

Ultraviolet (UV) radiation [1]

(iv) The bond energy of the $\text{C}-\text{Cl}$ bond is 346 kJ mol^{-1} .

Calculate the **wavelength** (in m) of radiation which breaks this bond.

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

$$\lambda = c h N_A \div \Delta E \quad \Delta E = 346 \text{ kJ mol}^{-1} = 346\,000 \text{ J mol}^{-1}$$

$$\lambda = (3.00 \times 10^8 \times 6.63 \times 10^{-34} \times 6.02 \times 10^{23}) \div 346\,000$$

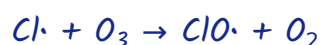
$$\lambda = 0.11974 \div 346\,000 = 3.4606 \times 10^{-7} \text{ m}$$

$$= 3.46 \times 10^{-7} \text{ m (3 s.f.)}$$

Wavelength = ... 3.46×10^{-7} m [5]

(v) Chlorine radicals catalyse the breakdown of ozone in the stratosphere.

Write equations to show how this occurs and give the overall equation.



Overall equation: $\text{O} + \text{O}_3 \rightarrow 2\text{O}_2$

[2]

(vi) Why is the breakdown of ozone in the stratosphere harmful to humans?

Ozone absorbs (removes) UV radiation, so if ozone breaks down more UV reaches the Earth's surface.
UV causes sunburn, skin cancer, damage to DNA and damage to the eyes. [2]

(b) CH_3Cl reacts with ammonia to give an amine salt.



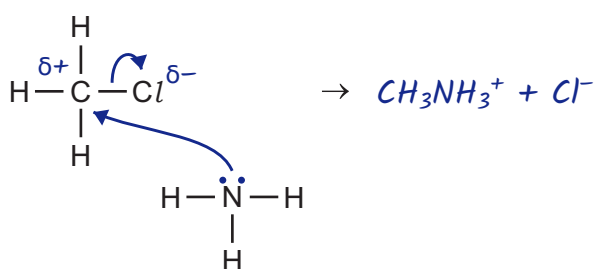
Ammonia is acting as a nucleophile here.

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

An electron pair donor: it donates a lone pair of electrons to form a new (dative covalent) bond. [1]

(ii) Show the mechanism of **Equation 1.1**.

Use curly arrows and show relevant lone pairs and the ionic products.



[2]

(iii) The product of **Equation 1.1** is a salt of CH_3NH_2 .

Give the systematic name for CH_3NH_2 .

Methylamine [1]

(c) The reaction between a haloalkane and hydroxide ions is a nucleophilic substitution reaction.

A student reacts 1-chlorobutane, 1-bromobutane and 1-iodobutane separately with aqueous sodium hydroxide.

Which will react fastest and why?

1-iodobutane ($\text{C}_4\text{H}_9\text{I}$) reacts fastest,
because the C-I bond is the weakest of the three (lowest bond enthalpy), so
it breaks most easily. [2]

2 Some students study the nitrogen compounds in the soil.

(a) How many neutrons are in an atom of ^{14}N ?

7 [1]

(b) The students make ammonia from a fertiliser containing NH_4^+ ions.

Identify the reagent that they use.

Sodium hydroxide solution, NaOH(aq) (and warm) [1]

(c) The students add an aqueous solution of ammonia to a solution of FeSO_4 .
A precipitate forms.

Give the colour of the precipitate and write an **ionic** equation for its formation.

Include state symbols.

Colour: *Green*

Ionic equation: *$\text{Fe}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_2(\text{s})$*

[3]

(d) The students read that ammonium ions are oxidised to NO_2^{-} by bacteria in the soil.

(i) Give the systematic name of NO_2^{-} .

Nitrate(III) ion [1]

(ii) The students add acid to $\text{NaNO}_2(\text{s})$ in a test tube.
A colourless gas **A** (with nitrogen in the +2 oxidation state) and NO_3^{-} ions are produced.

Gas **A** turns to a brown gas **B** at the top of the test tube.

Suggest the **formula** of the brown gas **B**.

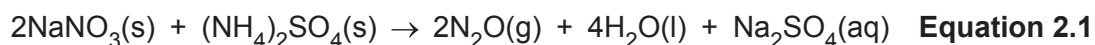
Suggest an **ionic** equation for the formation of **gas A** from acidified NO_2^{-} ions.

Formula of brown gas **B**: *NO_2*

Ionic equation: *$3\text{NO}_2^{-}(\text{aq}) + 2\text{H}^{+}(\text{aq}) \rightarrow 2\text{NO}(\text{g}) + \text{NO}_3^{-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$*

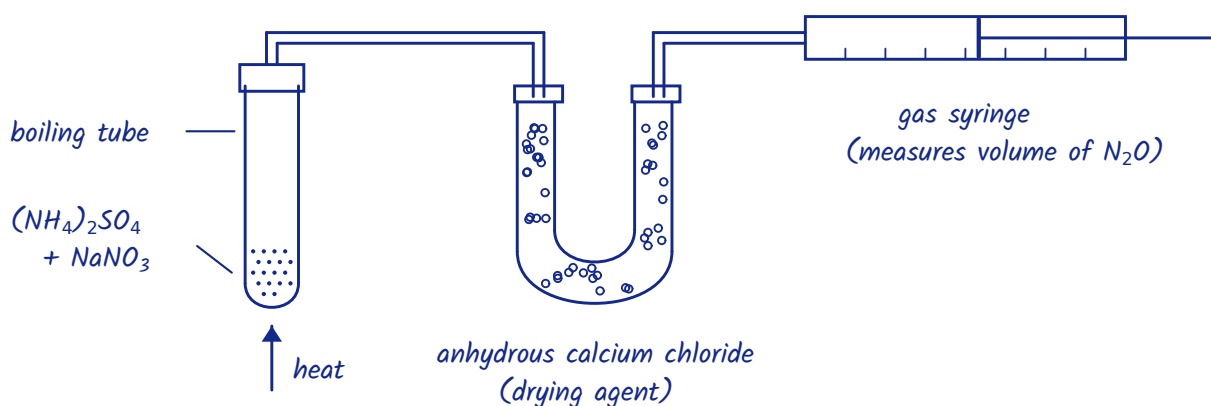
[3]

- (e) The students read that a sample of $\text{N}_2\text{O}(\text{g})$ can be prepared by heating a mixture of the solids NaNO_3 and $(\text{NH}_4)_2\text{SO}_4$.



- (i) The students want to test **Equation 2.1** by measuring the volume of **dry** N_2O produced by heating $(\text{NH}_4)_2\text{SO}_4$ with NaNO_3 .

Draw a labelled diagram of an apparatus they could use.



[4]

- (ii) The students heat 0.20 g of $(\text{NH}_4)_2\text{SO}_4$ with excess NaNO_3 .

Calculate the volume of N_2O (in cm^3) that would be formed at 20°C and 105 kPa.

$$M_r \text{ of } (\text{NH}_4)_2\text{SO}_4 = 132.1$$

$$n((\text{NH}_4)_2\text{SO}_4) = 0.20 \div 132.1 = 1.514 \times 10^{-3} \text{ mol}$$

$$n(\text{N}_2\text{O}) = 2 \times 1.514 \times 10^{-3} = 3.028 \times 10^{-3} \text{ mol}$$

$$V = nRT \div p = (3.028 \times 10^{-3} \times 8.314 \times 293) \div (105 \times 10^3)$$

$$V = 7.025 \times 10^{-5} \text{ m}^3 = 70.2 \text{ cm}^3$$

$$\text{Volume} = \dots\dots\dots 70.2 \dots\dots\dots \text{cm}^3 \quad [4]$$

- (f) Another oxide of nitrogen contains 37% nitrogen by mass.

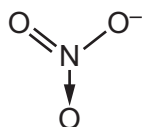
Calculate the formula of the oxide.

$$\text{N} : 37 \div 14.0 = 2.64 \quad \text{O} : 63 \div 16.0 = 3.94$$

$$\text{O} : \text{N} = 3.94 \div 2.64 = 1.49 \approx 1.5, \text{ so } \text{N} : \text{O} = 2 : 3$$

$$\text{Formula} = \dots\dots\dots \text{N}_2\text{O}_3 \dots\dots\dots [2]$$

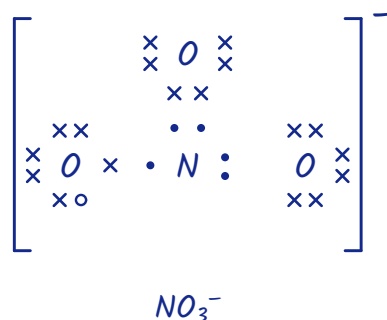
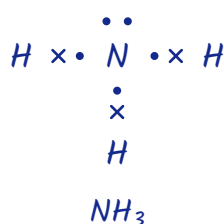
(g)* An NO_3^- ion can be represented as shown:



A student says that NH_3 and NO_3^- have the same shape and bond angles.

Discuss this, drawing 'dot-and-cross' diagrams and giving chemical explanations for the shapes and bond angles.

'Dot-and-cross' diagrams



• N electron × H / O electron ○ extra electron (charge)

NH_3 : N has 4 groups (areas) of electron density: 3 bonding pairs and 1 lone pair. Electron pairs repel and get as far apart as possible to minimise repulsion, so they are arranged tetrahedrally. Lone pair to bond pair repulsion is greater than bond pair to bond pair repulsion (the lone pair takes up more room), so the bond angle is reduced by about 2.5° from 109.5° to 107° . NH_3 is pyramidal.

NO_3^- : N has 3 groups (areas) of electron density (the double bond counts as one group) and no lone pairs. These repel equally and get as far apart as possible, so NO_3^- is trigonal planar with bond angles of 120° . [6]

Extra answer space if required.

So the student is wrong: NH_3 is pyramidal (107°) because it has 4 electron groups including a lone pair, but NO_3^- is trigonal planar (120°) because it has 3 groups and no lone pair.

- 3 Some scientists investigate the reaction of nitrogen monoxide with chlorine.

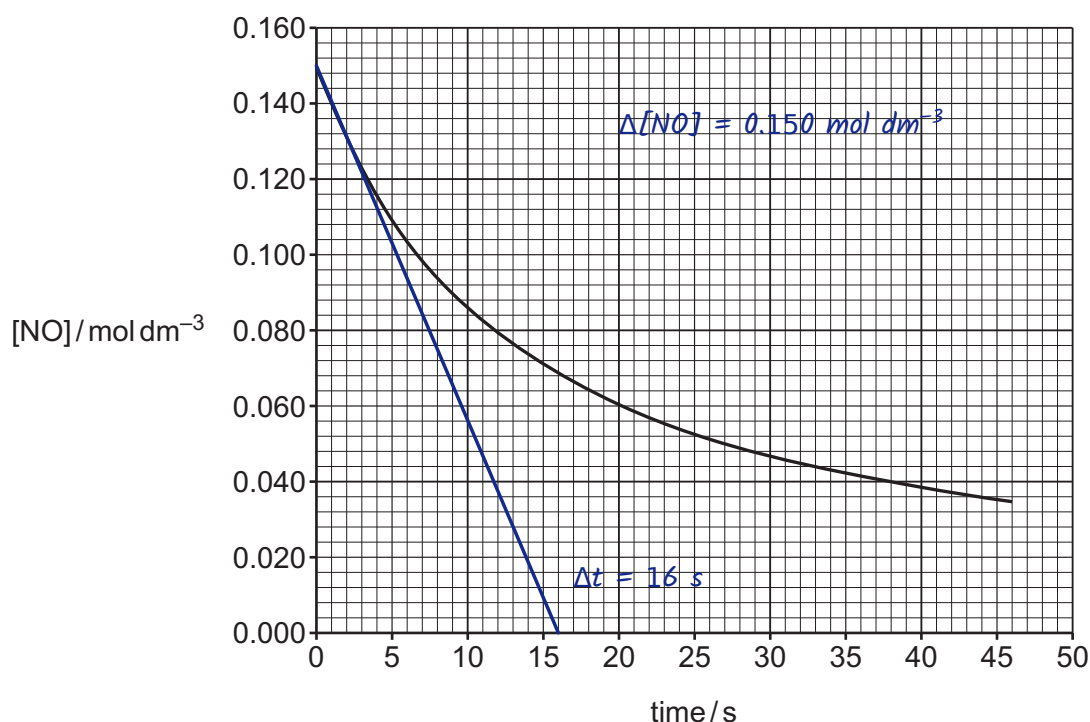
The reaction is:



The scientists wish to determine the order of the reaction with respect to NO.

They start their experiment by mixing a known concentration of NO with a large excess of Cl_2 .

They then measure the concentration of NO over time and plot a graph of [NO] against time.



- (a) Explain why a large excess of Cl_2 is required.

So that $[\text{Cl}_2]$ stays (virtually) constant during the experiment, so only the change in $[\text{NO}]$ affects the rate. [1]

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

Show your working on the graph.

tangent drawn at $t = 0$:

$$\text{gradient} = -(0.150 - 0.000) \div (16 - 0) = -0.0094 \text{ mol dm}^{-3} \text{s}^{-1}$$

$$\text{initial rate} = 9.4 \times 10^{-3} \text{ mol dm}^{-3} \text{s}^{-1}$$

$$\text{Initial rate} = 9.4 \times 10^{-3} \text{ mol dm}^{-3} \text{s}^{-1} \quad [2]$$

- (c) The scientists measure the initial rates of reaction for other NO concentrations.

Their results are shown in **Table 3.1**.

Table 3.1

$[\text{NO}] / \text{mol dm}^{-3}$	$[\text{NO}]^2 / (\text{mol dm}^{-3})^2$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
8.59×10^{-2}	7.38×10^{-3}	3.28×10^{-3}
6.10×10^{-2}	3.72×10^{-3}	1.65×10^{-3}
4.75×10^{-2}	2.26×10^{-3}	1.00×10^{-3}
3.89×10^{-2}	1.51×10^{-3}	0.67×10^{-3}

The scientists plot initial rate against $[\text{NO}]$ and discover this does **not** give a straight line.

- (i) What can the scientists conclude from this?

The reaction is not first order with respect to NO (rate is not proportional to $[\text{NO}]$). [1]

- (ii) Fill in the missing value in **Table 3.1**.

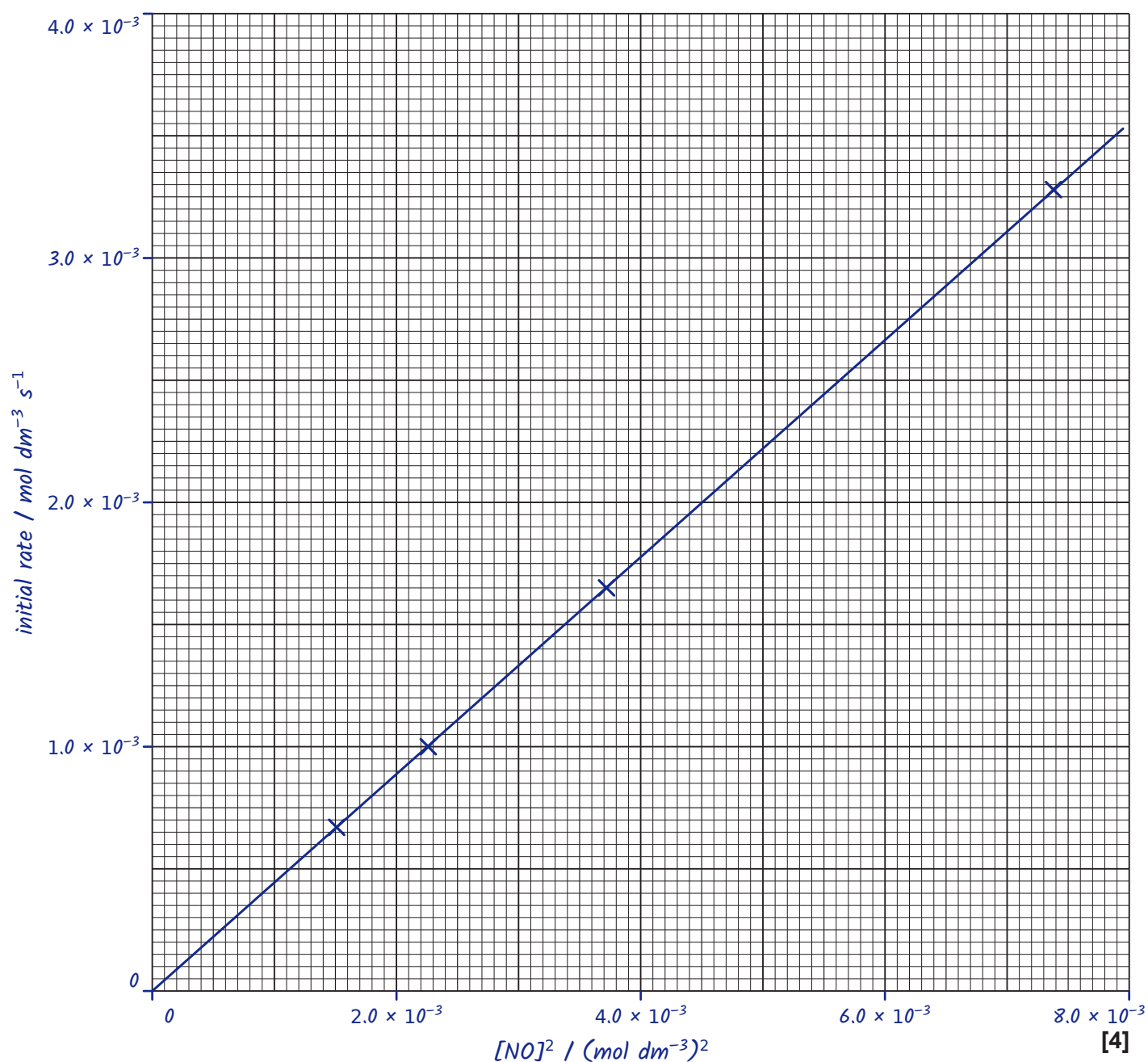
[1]

(iii) Plot a graph of initial rate against $[\text{NO}]^2$.

Use the data in **Table 3.1**.

Include the origin.

Draw the line of best fit.



(iv) Explain why the graph shows that the reaction is second order with respect to NO.

The graph is a straight line through the origin, so the initial rate is directly proportional to $[\text{NO}]^2$. [1]

(d) The scientists find that the reaction is first order with respect to Cl_2 .

(i) Complete the rate equation for the reaction.

$$\text{Rate} = k \times [\text{NO}]^2 [\text{Cl}_2]$$

[1]

(ii) Give the units of the rate constant, k .

$$\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$$

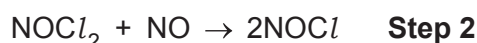
[1]

(iii) Explain why the value of the rate constant **cannot** be calculated from data in this question.

The concentration of Cl_2 is not known (it is only described as a large excess)

[1]

(iv) The scientists conclude that a possible mechanism is as shown below, with **step 2** being rate-determining.



Give the meaning of rate-determining step and explain why the scientists conclude that **Step 2** is the rate-determining step.

Meaning The slowest step in the mechanism, which controls (limits) the overall rate of reaction.

Explanation The rate equation contains $[\text{NO}]^2$ and $[\text{Cl}_2]$. $[\text{NOCl}_2]$ depends on $[\text{NO}]$ and $[\text{Cl}_2]$ (from step 1), and step 2 uses NOCl_2 and another NO , so the rate of step 2 depends on $[\text{Cl}_2]$ and $[\text{NO}]^2$, matching the rate equation.

[3]

11
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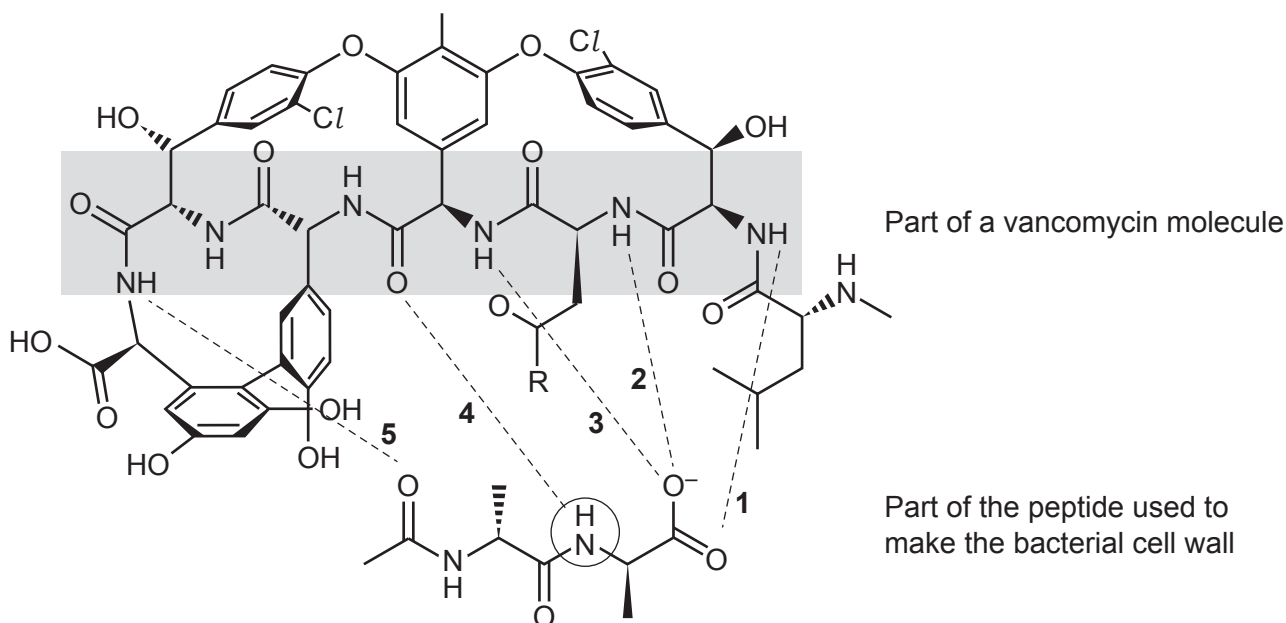
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4 This question is about molecular recognition.

- (a) Vancomycin is an antibacterial drug. It binds with peptides that bacteria use to make their cell walls. When the vancomycin binds, the process of making cell walls is disrupted, so the bacteria cannot grow.

Fig. 4.1 shows part of a vancomycin molecule bonded to part of the peptide.

Fig. 4.1



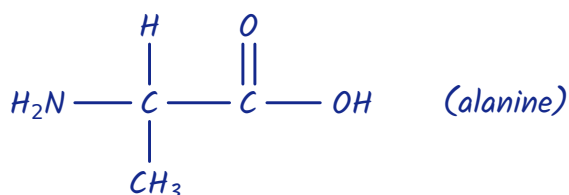
- (i) Vancomycin has a polypeptide chain. The area shaded grey represents the primary structure. In order for vancomycin to function, the primary structure must be held in a definite shape. This enables intermolecular bonds 1, 2, 3, 4 and 5 to form.

Describe how the primary structure is held in this definite shape in vancomycin.

...The R groups (side chains) of the amino acids are covalently bonded to each other (cross-linked)..... [1]

- (ii) The part of the **peptide** shown at the bottom of Fig. 4.1 is made from a repeat of the same amino acid.

Give the structure of this amino acid.



[1]

- (iii) Name the **type** of intermolecular bond shown by the numbers **1**, **4** and **5** and suggest why these bonds are weaker than bonds **2** and **3**, even though they are of similar length.

Hydrogen bonds.
 In bonds 1, 4 and 5 the $H^{\delta+}$ is attracted to an $O^{\delta-}$ (a partial negative charge), not to an O^- .
 In bonds 2 and 3 the $H^{\delta+}$ is attracted to the full negative charge on O^- ; the attraction between $H^{\delta+}$ and O^- is stronger than between $H^{\delta+}$ and $O^{\delta-}$. [3]

- (iv) In the peptides from some bacteria, the circled NH in **Fig. 4.1** is replaced by an oxygen atom, O. These bacteria are resistant to vancomycin.

Suggest why vancomycin has less effect on these bacteria.

Bond 4 cannot form: the O has no H attached, so it cannot hydrogen bond with the O on the vancomycin chain.
 So there is less intermolecular bonding between vancomycin and the bacterial cell wall peptide, so it binds less well. [2]

- (b) The binding of vancomycin is an example of molecular recognition.

Many medicines have part of their molecule that interacts in this way.

Name this part of a medicine molecule.

Pharmacophore. [1]

- (c) Molecular recognition occurs in the formation of proteins from messenger RNA.

Explain this process.

mRNA carries the code for the protein as a sequence of base triplets (codons).
 Each tRNA has an anticodon, a triplet of bases complementary to a codon. At the ribosome the tRNA binds to the mRNA by complementary base pairing between its anticodon and the codon (hydrogen bonds between bases).
 Each tRNA with a particular anticodon carries a specific amino acid, so the amino acids are brought together in the order coded for by the mRNA and are joined by peptide bonds to build the protein.

[3]

- (d) Enzymes have a three-dimensional region that bonds with the substrate.

Name this region.

Active site [1]

- (e) Dyes attach themselves to fibres by a variety of bonds.

- (i) Acid dyes have SO_3^- groups. These groups form ionic bonds with nylon fabrics under acid conditions.

Explain how this occurs.

*In acid conditions the NH_2 (and NH) groups in nylon accept H^+ ions and
become NH_3^+ (and NH_2^+).
These positive ions form ionic bonds (electrostatic attraction) with the negative
 SO_3^- groups of the dye.* [2]

- (ii) Some dyes form instantaneous dipole–induced dipole bonds with certain fabrics.

Explain how instantaneous dipole–induced dipole bonds are formed.

*Electrons in a molecule are always moving randomly, so at any instant there
can be an unequal distribution of electron density (more electrons at one end
of the molecule than the other).
This creates an instantaneous dipole in the molecule.
The instantaneous dipole induces a dipole in a neighbouring molecule, and the
two dipoles attract each other.* [3]

- 5 This question refers to the Advance Notice Article Battery Tech Report: 'Lithium-Ion vs Vanadium Redox Flow Batteries (VRFB)' that is included as an Insert to this paper.

(a)* Explain why lithium has only one oxidation state in its compounds while vanadium has several.

Give electron configurations of atoms and several ions in your answer.

Lithium is an s-block element: Li is $1s^2 2s^1$. It loses its one outer 2s electron to form Li^+ , $1s^2$, which has a full shell (the stable configuration of helium). Removing another electron would mean taking one from the full inner 1s shell, close to the nucleus, which needs far too much energy. So Li^+ is the only stable ion and lithium only has the +1 oxidation state in its compounds.

Vanadium is a d-block (transition) element: V is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$. The 4s and 3d sub-shells are very close in energy, so vanadium can lose different numbers of electrons (first the 4s, then the 3d electrons) without a big jump in energy, giving several stable ions with different electron configurations:

V^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$ ([Ar] $3d^3$), oxidation state +2

V^{3+} [Ar] $3d^2$, +3 V^{4+} (in VO^{2+}) [Ar] $3d^1$, +4

V^{5+} (in VO_2^+) [Ar] $3d^0$ = [Ar], +5

So vanadium has several oxidation states (+2, +3, +4 and +5) because of its [6]

Extra answer space if required.

partly filled 3d sub-shell, whereas lithium can only form +1.

.....

.....

.....

.....

.....

.....

(b) Table 5.1 shows some redox potentials.

Table 5.1

Redox system	$E^\ominus/\text{V}$
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$	-0.26
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{VO}_2^+(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.34
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{VO}_2^+(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+1.00

(i) When the VRFB is delivering a current, V(V) is reduced to V(IV) and V(II) is oxidised to V(III).

Write the ionic equation and give the $E^\ominus_{\text{cell}}$ for the overall reaction that occurs.

Include state symbols.

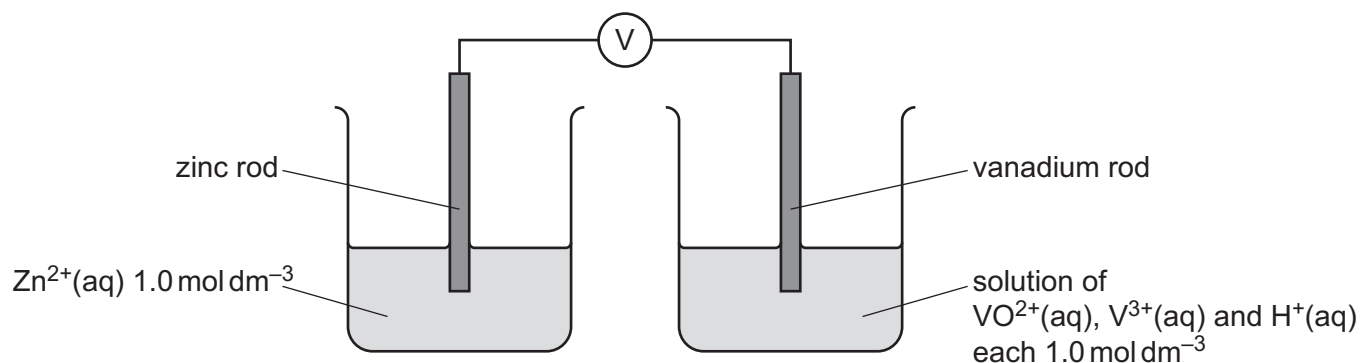
Ionic equation:



$$E^\ominus_{\text{cell}} \dots\dots\dots +1.26 \dots\dots\dots \text{V} \quad [2]$$

(ii) A student sets up a cell to measure the $E^\ominus_{\text{cell}}$ for $\text{VO}_2^+/\text{V}^{3+}$ against Zn^{2+}/Zn at 298 K.

Here is a diagram of the student's cell.



The student has made **two** mistakes in setting up the cell.

Describe these mistakes **and** how they should be corrected:

Mistake 1 *There is no salt bridge: add a salt bridge (filter paper soaked in saturated $\text{KNO}_3(\text{aq})$) dipping into both solutions.*

Mistake 2 *The vanadium rod should not be used: replace it with a platinum electrode in the $\text{VO}_2^+/\text{V}^{3+}$ solution.*

[2]

- (iii) A student has powdered samples of the metals (silver, tin and zinc) shown in **Table 5.1**, and an acidic solution of $\text{VO}_2^+(\text{aq})$.

The student wants to obtain a solution containing V^{3+} ions.

Explain why the student would use tin rather than silver or zinc.

Write the overall equation for the student's reaction.

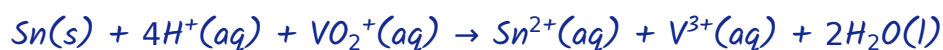
VO_2^+ must be reduced to V^{3+} but not to V^{2+} .

Tin ($E^\ominus = -0.14 \text{ V}$) will reduce V(V) to V(IV) and $\text{V(IV)} (\text{VO}^{2+})$ to V^{3+} , because -0.14 V is more negative than $+1.00 \text{ V}$ and $+0.34 \text{ V}$, but it will not reduce V^{3+} to V^{2+} as -0.14 V is more positive than -0.26 V .

Silver ($+0.80 \text{ V}$) will not reduce V(IV) to V^{3+} ($+0.80 \text{ V}$ is more positive than $+0.34 \text{ V}$).

Zinc (-0.76 V) will reduce V^{3+} on to V^{2+} .

Overall equation:



[4]

(c) The two types of battery have properties that are suited to different uses.

(i) From the article, give **two advantages** of Li-ion batteries over VRFBs as **batteries for electric vehicles**.

Advantage 1 *Very high (unmatched) energy density, so lots of energy is stored in a small, light battery.*

Advantage 2 *Responds quickly to changes in power demand (and has low self-discharge).*

[2]

(ii) From the article, give **two advantages** of VRFBs over Li-ion batteries for large-scale use in **storing energy from an array of solar cells**.

Advantage 1 *Energy capacity can be expanded simply by adding more solution to a larger tank.*

Advantage 2 *Can run at 100% capacity for a long time and handle more charge/discharge cycles (and will not cause fires).*

[2]

(d) Both types of battery have a separator in the middle.

Give the formulae of the particles that pass through the separators in each battery when they are in use.

Li-ion battery *Li^+*

VRFB *H^+*

[1]

(e) Solutions of vanadium compounds are coloured.

(i) Explain why they are coloured, selecting terms from the following list as required:

absorption

complementary

emission

transmission

The vanadium ions absorb certain frequencies (wavelengths) of visible light; the energy absorbed promotes d electrons to a higher d energy level. The remaining frequencies are transmitted, and we see the complementary colour of the light absorbed.

[2]

(ii) Explain why the colours are different.

The frequency of light absorbed depends on the energy gap, ΔE , between the d energy levels ($\Delta E = hf$). ΔE varies with the vanadium ion (oxidation state) and complex present, so different frequencies are absorbed and different colours are transmitted.

[2]

END OF QUESTION PAPER

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