H032/01
Breadth in Chemistry
June 2016

Model Answers

Level	AS Level
Subject	Chemistry A
Exam Board	OCR
Paper Code	H032/01
Paper	Breadth in Chemistry
Booklet	Model Answers

Time allowed: **90 minutes**

Score: **/70**

Percentage: **/100**

Grade Boundaries:

A	B	C	D	E
>79%	69%	60%	50%	41%

Which row shows the atomic structure of $^{37}Cl^{-}$?

	protons	neutrons	electrons
A	17	18	20
B	17	20	18
C	18	19	17
D	20	17	21

[1]

- From the Periodic Table C*l* has a proton number of 17 and the mass number is given in the question as 37, therefore $^{37}Cl^{-}$ has 37 - 17 = 20 neutrons.
- It has a single negative charge so the number of electrons must be 1 **more** than the number of protons, hence there are 17 + 1 = 18 electrons.
- A, C and D are therefore incorrect.

What is the formula of ammonium sulfide?

A. NH_4S

B. NH_4SO_4

C. $(NH_4)_2S$

D. $(NH_4)_2SO_4$ **[1]**

- Each ammonium ion has a single positive charge (NH_4^+) and the sulfide ion has a -2 charge (S^{2-}).
- The overall charge has to be zero so there must be one sulfur atom and two ammonium ions since (2 x 1) + (-2) = 0.
- A and B are incorrect as the formulae written are not neutral.
- D is incorrect as the formula written is for ammonium sulfate which contains the sulfate group, SO_4^{2-}.

Calcium nitrate, $Ca(NO_3)_2$, decomposes when heated, as shown below.

$$Ca(NO_3)_2(s) \rightarrow CaO(s) + 2NO_2(g) + \frac{1}{2}O_2(g)$$

A student decomposes 0.00500 mol of $Ca(NO_3)_2$ and collects the gas that is produced.

Calculate the volume of gas that the student should expect to collect, measured at room temperature and pressure.

A. 60 cm^3

B. 120 cm^3

C. 240 cm^3

D. 300 cm^3 **[1]**

- The molar gas volume is 24.0 dm^3 mol^{-1} at RTP.
- From the balanced equation, 1 mole of $Ca(NO_3)_2$ produces 2 moles of NO_2 and 0.5 moles of O_2.
- Therefore 0.005 moles of $Ca(NO_3)_2$ produce 0.005 x 2.5 = 0.0125 moles of gaseous product.
- Since 1 mole of gas occupies 24.0 dm^3, then 0.0125 moles occupies 24.0 dm^3 x 0.0125 = 0.3 dm^3.
- Convert dm^3 to cm^3 by multiplying by 1000, so 0.3 dm^3 = 300 cm^3, hence D is the correct answer.
- A, B and C are thus incorrect.

Which equation is **not** a neutralisation reaction?

A. $Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$

B. $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

C. $K_2CO_3(s) + 2HNO_3(aq) \rightarrow 2KNO_3(aq) + H_2O(l) + CO_2(g)$

D. $NH_3(aq) + HCl(aq) \rightarrow NH_4Cl(aq)$

[1]

- Neutralization reactions occur when H^+ ions donated by an acid react with OH^- ions donated by a base.
- A salt and water is formed and in the case of the base being a **carbonate**, carbon dioxide gas is also released.
- Equation A is an acid-metal reaction which produces hydrogen gas and the corresponding metal salt. Water is **not** produced hence it is not a neutralization reaction.
- Equations B and C are neutralization reactions in which water, salt and CO_2 in equation C are produced.
- Equation D is also a neutralization reaction in which aqueous NH_3 acts as a base as it partially dissociates in water to produce NH_4^+ and OH^- ions.

What is the oxidation number of nitrogen in $Mg(NO_3)_2$?

A –3

B +2

C +5

D +6

[1]

- The sum of the oxidation numbers in a neutral compound is always **zero**.
- The oxidation state of oxygen is -2, there are 6 oxygen atoms which gives 6 x -2 = -12.
- Magnesium is a Group II metal hence its oxidation state is +2.
- That leaves -12 + 2 = -10 which must be accounted for by the nitrogen atoms.
- There are two nitrogen atoms, hence each one must have an oxidation number of +5, since -10 + (2 x 5) = 0.
- A, B and D are therefore incorrect.

How many orbitals are occupied in a silicon atom?

A. 5

B. 7

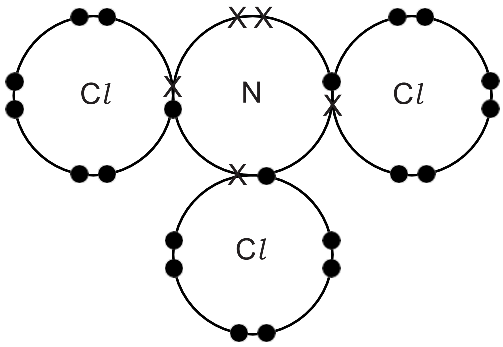
C. 8

D. 9

[1]

- The atomic number of silicon is 14 so its electronic configuration is:
    - $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$
- Each s-subshell has one orbital and each p-subshell has three orbitals.
- Counting the electrons and orbitals we get:
    - 1s: 2 electrons and 1 orbital
    - 2s: 2 electrons and 1 orbital
    - 2p: 6 electrons and 3 orbitals
    - 3s: 2 electrons and 1 orbital
    - 3p: 2 electrons and 3 orbitals
- All fourteen electrons are accounted for and adding up the orbitals gives a total of 9, hence D is the correct answer.
- A, B and D are thus incorrect.

A '*dot-and-cross'* diagram for nitrogen trichloride, NCl_3, is shown below.



Which row shows the correct shape and bond angle in a molecule of NCl_3?

	Name of shape	**Bond angle**
A	Pyramidal	104.5°
B	Pyramidal	107°
C	Tetrahedral	107°
D	Trigonal planar	120°

[1]

- There are three **bonding pairs** of electrons and one **lone pair** in nitrogen trichloride.
- That means there are a total of four pairs which make the molecule similar in shape to a tetrahedral.
- The **lone pair** of electrons on the nitrogen atom, however, repel the bonding pairs slightly and reduce the angle from a normal tetrahedral of 109^0 to 107^0 degrees.
- This angle and shape correspond to a pyramidal molecule.
- A, C and D are therefore incorrect.

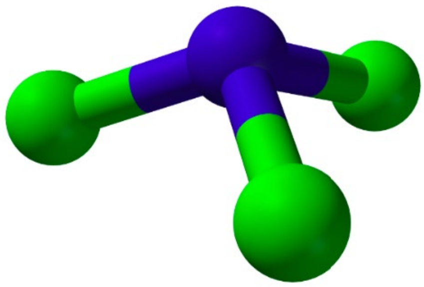


Image of NCl_3 showing lone pair repulsion on the N atom causing the N-H bonds to angle downwards

Exam Tip

Your first step in questions on shapes of molecules should be to identity the **bonding** and **non-bonding** pairs of electrons. This is easiest done using a dot-and-cross diagram, which you should draw if one is not given in the question.

What is the shape around the carbon atoms in graphene?

A. linear

B. pyramidal

C. tetrahedral

D. trigonal planar

[1]

- In graphene each carbon atom is bonded to **three** others, forming a flat sheet.
- Each sheet is composed of carbon atoms that are **sp2 hybridized** which form **planar hexagonal** shapes.
- The three bonds in each carbon atom move as far apart from each other as possible to minimize electron pair repulsion, forming a triangle with bond angles of **120^0**.
- This geometry is called trigonal planar.
- A, B and C are thus incorrect.

Electron configurations for atoms of different elements are shown below.

Which electron configuration represents the element with the largest first ionisation energy?

A $1s^2 2s^2$

B $1s^2 2s^2 2p^4$

C $1s^2 2s^2 2p^6$

D $1s^2 2s^2 2p^6 3s^2$

- Start this question by first identifying the elements in each option: **[1]**
  - Option A is beryllium
  - Option B is oxygen
  - Option C is neon
  - Option D is aluminium
- First ionization energies increase moving **across** the Periodic Table from left to right.
- Neon lies on the far right of the table, is a noble gas and has a full outer shell making it very stable and thus very difficult to ionize.
- It therefore has the highest first ionisation energy.
- A, B and D are thus incorrect.

Successive ionisation energies of four elements in Period 3 are shown below.

Which letter could represent magnesium?

	Ionisation energy / kJ mol^{-1}				
	1st	2nd	3rd	4th	5th
A	1251	2298	3822	5159	6542
B	738	1451	7733	10543	13630
C	496	4563	6913	9544	13352
D	578	1817	2745	11577	14842

[1]

- The electronic configuration for magnesium is $1s^2 2s^2 2p^6 3s^2$.
- Magnesium characteristically shows a large jump on going from the **second** to the **third** ionisation energy.
- This is because the first two ionisation energies correspond to electrons which are removed from the 3s sub-shell which is relatively easy to do as it is furthest away from the nucleus.
- The third electron, however, has to be removed from the 2p sub-shell, where it is located closer to the nucleus and hence has a greater attraction, so much more energy is required to remove it.
- A, C and D are incorrect as the ionization energies in each option do not correspond with the pattern for magnesium.

A student adds aqueous sodium carbonate to one test-tube and aqueous silver nitrate to a second test-tube.
The student adds dilute sulfuric acid to each test-tube.

Which row has the correct observations?

	Aqueous sodium carbonate	Aqueous silver nitrate
A	no change	precipitate
B	no change	no change
C	effervescence	no change
D	effervescence	precipitate

[1]

- Sulfuric acid and aqueous sodium carbonate react together to produce carbon dioxide gas (effervescence), sodium sulfate and water:
  - $H_2SO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + H_2O + CO_2$
- On reaction with aqueous silver nitrate, sulfuric acid produces the **precipitate silver nitrate** and nitric acid:
  - $H_2SO_4 + 2AgNO_3 \rightarrow Ag_2SO_4 + 2HNO_3$
- Only option D matches the observations of the reaction.
- A and B are incorrect as carbon dioxide gas is produced which is observed as effervescence.
- C is incorrect as the the silver sulfate precipitate is formed in this reaction.

The enthalpy change of formation of butane can be calculated using the enthalpy changes of combustion, $\Delta_c H$, below.

Substance	C(s)	H_2(g)	C_4H_{10}(g)
$\Delta_c H$ / kJ mol^{-1}	–394	–286	–2877

Calculate the enthalpy change of formation of C_4H_{10}(g).

$$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$$

A –2197 kJ mol^{-1}

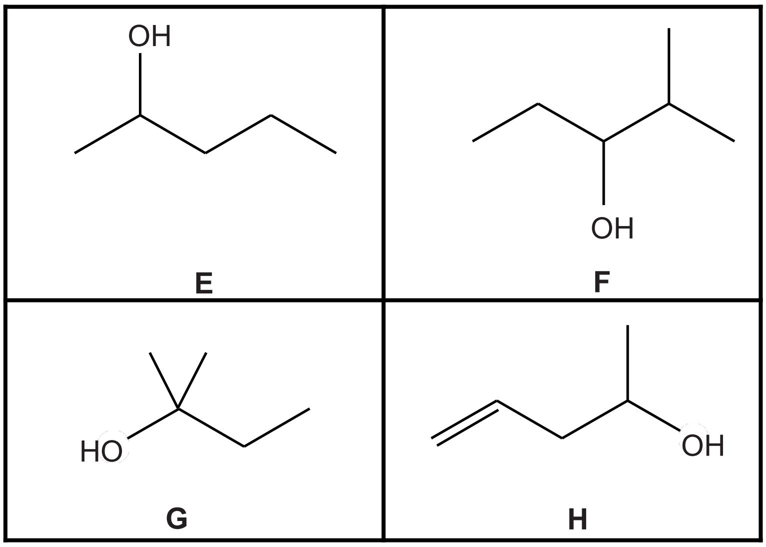
B –129 kJ mol^{-1}

C +129 kJ mol^{-1}

D +2197 kJ mol^{-1} **[1]**

- Using Hess's Law we can calculate the total enthalpy change by adding up the enthalpy changes of combustion in each step.
- ΔH C = 4 x -394 = -1576 kJ mol^{-1}
- ΔH H = 5 x -286 = -1430 kJ mol^{-1}
- ΔH C_4H_{10} = +2877 (The negative sign here has been changed as it is a product in the target equation but a reactant in the combustion equation on which the data is based).
- Adding up all enthalpies: (-1576) + (-1430) + 2877 = -129 kJ mol^{-1}
- A, C and D are thus incorrect.

The skeletal formulae of four alcohols, **E**, **F**, **G** and **H**, are shown below.



Which pair of alcohols are structural isomers of each other?

A. **E** and **F**

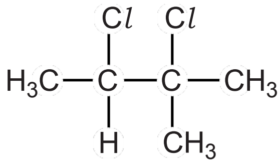
B. **E** and **G**

C. **E** and **H**

D. **F** and **G** **[1]**

- Structural isomers are molecules that have the same molecular formula but in which the atoms are connected to each other differently.
- Approach this question by writing down the molecular formula for each molecule:
  - Structure E is $C_5H_{11}OH$
  - Structure F is $C_6H_{13}OH$
  - Structure G is $C_5H_{11}OH$
  - Structure H is C_5H_9OH
- Only structures E and G share the same molecular formula hence option B is the correct answer.
- A, C and D are thus incorrect.

What is the name of the following compound?



A. 1,2-dichloro-1,2-dimethylpropane

B. 2,3-dichloro-2,3-dimethylpropane

C. 2,3-dichloro-2-methylbutane

D. 2,3-dichloro-3-methylbutane

[1]

- There are four carbon atoms in the carbon chain numbered 1 - 4 from left to right, hence the chain is butane, so options A and B can be disregarded.
- Carbons 2 and 3 are attached to chlorine atoms and the methyl group is attached to carbon atom number 3, hence the name is 2,3-dichloro-3-methylbutane.
- Thus option D is also incorrect.

Which compound has non-polar molecules?

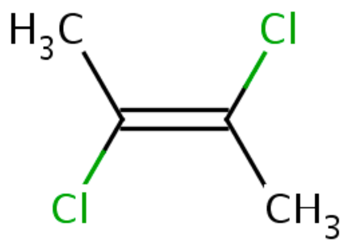
A *E*-1,2-dichlorobut-2-ene

B *E*-2,3-dichlorobut-2-ene

C *Z*-2,3-dichlorobut-2-ene

D *Z*-1,4-dichlorobut-2-ene **[1]**

- Draw out each molecule making sure that the E/Z notation and numbering is correct.
- It becomes clear that compound B, due to its symmetry, has non-polar molecules.
- This is as the polarity of the C*l* atoms acts in opposite directions which cancel each other.

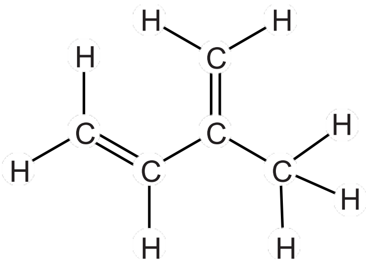


The symmetrical shape of E-2,3-dichlorobut-2-ene renders the molecule non-polar

Exam Tip

For identifying polar/non-polar compounds, it is much easier to determine the symmetry of the compound by drawing out the structural formula, rather than from the molecular formula.

The displayed formula for a hydrocarbon is shown below.



How many σ and π bonds are present in a molecule of this hydrocarbon?

	σ bonds	π bonds
A	2	4
B	10	2
C	10	4
D	12	2

[1]

- Each single C-C bond contains **1 σ bond** and each C=C bond contains **1 σ** and **1 π bond**.
- Picking a specific point on the molecule and counting around from left to right there are 10 single bonds and 2 double bonds.
- That gives a total of 12 σ bonds and 2 π bonds.
- A, B and C are thus incorrect.

Chlorine reacts with 1-chloropropane in the presence of ultraviolet radiation via a radical substitution mechanism.

Which equation shows a propagation step in the mechanism for this reaction?

A $Cl_2 \rightarrow \bullet Cl + \bullet Cl$

B $\bullet Cl + \bullet C_3H_6Cl \rightarrow C_3H_6Cl_2$

C $C_3H_7Cl + \bullet Cl \rightarrow C_3H_6Cl_2 + \bullet H$

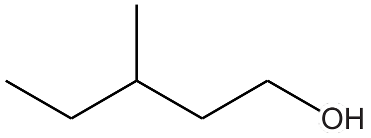
D $\bullet Cl + C_3H_7Cl \rightarrow \bullet C_3H_6Cl + HCl$

[1]

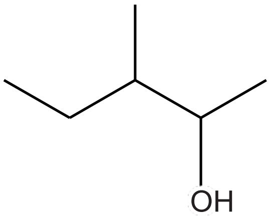
- Radical substitution reactions occur in three stages: initiation, propagation and termination.
- The propagation stage occurs in two steps and is a chain reaction.
- In the first step the halogen radical (in this case chlorine) reacts with a C-H bond on the hydrocarbon, producing the hydrocarbon radical $\bullet C_3H_6Cl$ and HCl.
- A, B are incorrect as they show termination stages.
- C is incorrect as it shows a displacement reaction.

Which alcohol can be oxidised by $K_2Cr_2O_7$ and H_2SO_4 to form a ketone?

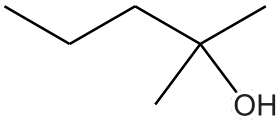
A



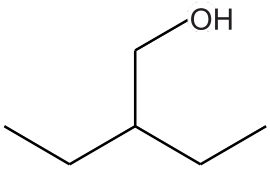
B



C



D



[1]

- Only **secondary** alcohols undergo oxidation to produce ketones.
- In molecule B, the -OH group is attached to a carbon that is attached to two other carbon atoms and a hydrogen atom, hence it is a secondary alcohol.
- A and D are incorrect as these are primary alcohols which produce aldehydes or carboxylic acids upon oxidation, depending on the reaction conditions.
- C is incorrect as this is a tertiary alcohol which resist oxidation.

A reaction sequence is shown below:

Step 1 $CH_3CH{=}CHCH_3$ + HBr → $CH_3CH_2CHBrCH_3$

Step 2 $CH_3CH_2CHBrCH_3$ + NaOH → $CH_3CH_2CH(OH)CH_3$ + NaBr

Which type of reaction mechanism is involved in each step?

	Step 1	**Step 2**
A	electrophilic addition	electrophilic substitution
B	electrophilic addition	nucleophilic substitution
C	nucleophilic addition	electrophilic substitution
D	nucleophilic addition	nucleophilic substitution

[1]

- In the first stage of the sequence the H-Br bond breaks **heterolytically** in such a way that the bromine atom gets **both** of the bonding electrons after splitting.
- This leaves the highly **electrophilic H^+** which then attacks the carbon carbon double bond in step 1 which is therefore **electrophilic addition**.
- The bromine atom now has both electrons from the H-Br bond and forms the **nucleophile** which attacks the positive carbocation intermediate in step 2 which is therefore **nucleophilic substitution**.
- A, C and D are thus incorrect.

When heated with NaOH(aq), 1-iodobutane is hydrolysed at a much faster rate than 1-chlorobutane.

Which statement explains the different rates?

A. The C–I bond enthalpy is greater than the C–C*l* bond enthalpy.

B. The C–I bond is less polar than the C–C*l* bond.

C. The C–I bond has a C atom with a greater $\delta+$ charge than in the C–C*l* bond.

D. The C–I bond requires less energy to break than the C–C*l* bond.

[1]

- Both molecules are primary haloalkanes hence the structure of the molecule has no effect on the rate of reaction.
- The other factor which affects the rate of reaction in the hydrolysis of haloalkanes is the identity of the halogen.
- The strength of the halogen-carbon bond decreases as we move down Group 7 due to **increasing** atomic distances.
- Hence 1-chlorobutane reacts slower than 1-iodobutane as iodine sits **below** chlorine in Group 7, so less energy to break the C-I bond than the C-C*l* bond.
- A is incorrect as the opposite of this statement is the case.
- B and C are incorrect as bond polarity doesn't influence the rate of reaction.

A twenty pence coin contains copper and nickel.

(a) Copper and nickel each exist as a mixture of isotopes.

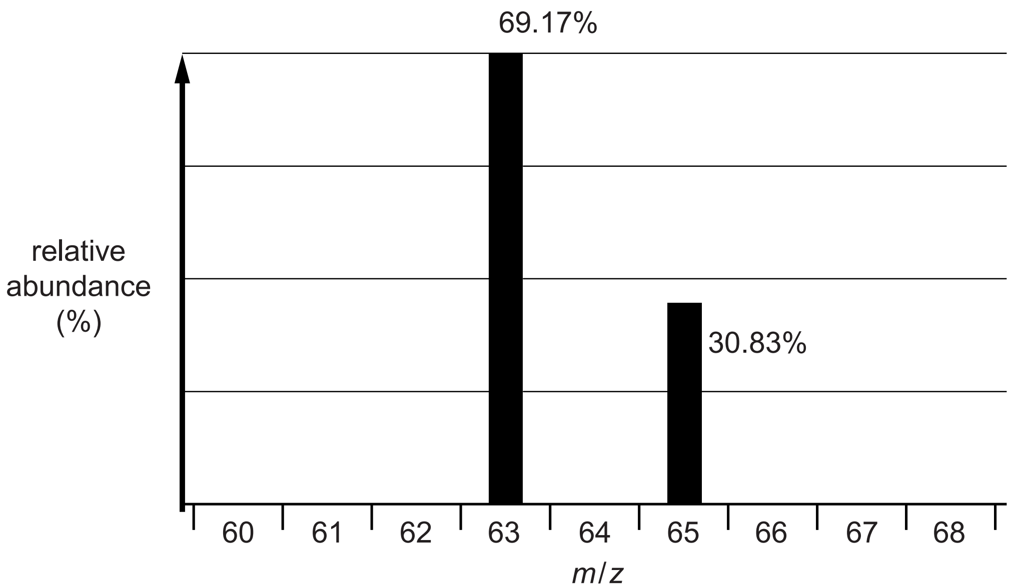
State the similarities and differences between the atomic structure of isotopes of the **same** element.

Similarities: (Same) number of protons AND electrons **[2]**

Differences: (Different) number of neutrons

From the definition of an isotope: Atoms of the same **element** with the same number of protons and different numbers of neutrons, or the same atomic number but different mass number.

(b) The copper used to make a batch of coins is analysed by mass spectrometry. The mass spectrum is shown below.



(i) Calculate the relative atomic mass of the copper used to make the coins.

Give your answer to **two** decimal places.

[2]

$$\frac{(63 \times 69.17) + (65 \times 30.83)}{100}$$

OR 63.6166 OR 63.617

= 63.62 (to 2 DP)

IGNORE any units with A_r

Multiply the relative abundance by the m/z ratio for each isotope. Then add these together and divide by 100 to calculate the relative atomic mass of the copper used in the coins.

(ii) One coin has a mass of 5.00 g and contains 84.0% of copper, by mass.

Calculate the number of copper atoms in one coin.

Give your answer in standard form and to **three** significant figures. **[2]**

Using 63.62: correct A_r of Cu from 21(b)(i)

n(Cu) = 5.00 × 0.840 / 63.62

= 4.2 / 63.62

= 0.066(0) (mol)

First calculate the number of moles of copper atoms.

Cu atoms = 0.0660 × 6.02 × 10^{23} = **3.97 × 10^{22}**

Must be calculated in standard form **AND** to 3 SF

Then use Avogadro's constant to calculate the number of individual copper atoms.

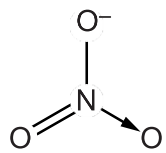
(c) Nickel(II) nitrate, $Ni(NO_3)_2$, can be prepared by reacting nickel(II) oxide with dilute nitric acid.

(i) Write the equation for this reaction.

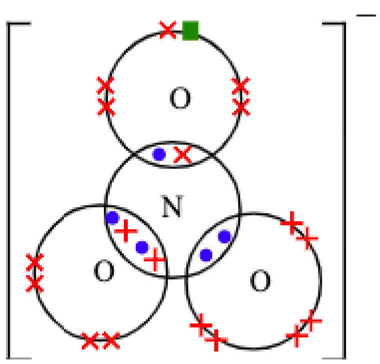
[1]

$NiO + 2HNO_3 \rightarrow Ni(NO_3)_2 + H_2O$

(ii) $Ni(NO_3)_2$ contains the NO_3^- ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond, as shown below.



Draw the '*dot-and-cross*' diagram for the NO_3^- ion, showing outer shell electrons only. Use a different symbol for the extra electron. **[2]**



Make sure that you represent the nitrogen and oxygen electrons using **different** symbols. The extra electron on the oxygen atom should also be shown with a different symbol as shown in the diagram.

(Total 9 marks)

This question is about several salts.

(a) A hydrated salt, compound **A**, is analysed and has the following percentage composition by mass:

Cr, 19.51%; C*l*, 39.96%; H, 4.51%; O, 36.02%.

Calculate the formula of compound **A**, showing clearly the water of crystallisation.

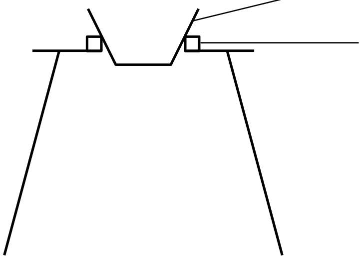
Show your working.

[3]

Step	Working Out			
1.Divide the percentage of each element by its RAM to calculate the molar ratio.	Chromium: $\frac{19.51}{52.0} = 0.375$	Chlorine: $\frac{39.96}{35.5} = 1.126$	Hydrogen: $\frac{4.51}{1.0} = 4.51$	Oxygen: $\frac{36.02}{16.0} = 2.25$
2.Divide across by smallest ratio to get lowest whole numbers.	$\frac{0.375}{0.375} = 1$	$\frac{1.126}{0.375} = 3$	$\frac{4.51}{0.375} = 12$	$\frac{2.25}{0.375} = 6$
3.Calculate the amount of water of crystallisation present and write out the formula using the ratios.	The ratio of H:O in the molecule is 12:6. Dividing this by the ratio of H:O in water molecules (2:1) gives 6. So there are 6 molecules of H_20, 1 atom of Cr and 3 of C*l*. The formula including water of crystallisation is thus: $CrCl_3.6H_2O$			

(b) A student carries out an experiment to determine the amount of water of crystallisation in the formula of another hydrated salt. The student intends to remove the water by heating the hydrated salt.

A diagram of the apparatus used by the student is shown below.



- The student adds the hydrated salt to the crucible and weighs the crucible and contents.
- The student heats the crucible and contents and allows them to cool.
- The student weighs the crucible and residue.

The student's results are shown below.

Mass of crucible + hydrated salt / g	16.84
Mass of crucible + residue after heating / g	16.26

(i) The maximum error in each mass measurement using the balance is ±0.005 g.

Calculate the percentage error in the mass of water removed. **[1]**

$\frac{2 \ x \ 0.005}{0.58}$ x 100 = 1.72%

Use the following equation:

% error = $\frac{uncertainty}{Measurement \ from \ apparatus}$ x 100

Two measurements were taken, each one with a maximum error of ± 0.005g, hence it must be multiplied by 2 and divided by the result. Multiplying by 100 provides the percentage.

(ii) Suggest **one** modification that the student could make to their method to reduce the percentage error in the mass of water removed.

[1]

Use balance weighing to 3/more decimal places

OR

Use a larger mass/amount

Either option is acceptable, however, it is more common to increase the accuracy by changing the apparatus used then by increasing the sample size.

(iii) The student is not sure that all the water of crystallisation has been removed.

How could the student modify the experiment to be confident that all the water of crystallisation has been removed?

[1]

Heat to constant mass.

This will remove any remaining water molecules which are not part of the water of crystallisation.

(c) A student prepares a solution of sodium sulfate, Na_2SO_4, by adding 6.25×10^{-2} mol dm^{-3} sulfuric acid, H_2SO_4, from a burette to 25.0 cm^3 of 0.124 moldm^{-3} NaOH in a conical flask.

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

Calculate the minimum volume of the H_2SO_4 that the student would need to completely react with the NaOH present.

[3]

Step	Working out
1.Calculate the moles of NaOH present	$0.124 \times \frac{25.0}{1000} = 3.1(0) \times 10^{-3}$ moles
2.Calculate the moles of H_2SO_4 needed to neutralise the moles of NaOH. Remember the molar ratio from the balanced equation is 2NaOH : $1H_2SO_4$	$\frac{3.10 \times 10^{-3}}{2} = 1.55 \times 10^{-3}$ moles
3.Convert moles to volume for H_2SO_4	$V(H_2SO_4) = 1.55 \times 10^{-3} \times \frac{1000}{6.25 \times 10^{-2}} = 24.8\ cm^3$

(d) Salts can also be prepared in redox reactions of metals with acids.
A student prepares a solution of aluminium sulfate by reacting aluminium with dilute sulfuric acid.

$$2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

Using oxidation numbers, show which element has been oxidised and which has been reduced in this reaction. State the changes in oxidation numbers, including all signs.

element oxidised..

oxidation number change: from .... to ....

element reduced ....

oxidation number change: from .... to.........................

[2]

Element oxidised: aluminium/Al 0 to +3

Aluminium as a reactant is in the elemental state hence its oxidation number is 0. In $Al_2(SO_4)_3$, each oxygen atom is in the -2 state, hence (-2 x 12) = -24. Each sulfur atom is in the +6 oxidation state, so 3 x 6 = 18. That leaves -24 + 18 = 6 which must be divided between the two aluminium atoms. Each one must therefore be in a +3 oxidation state for the overall charge of the molecule to be 0, hence the oxidation number changes from 0 to +3.

Element reduced: hydrogen/H/H^+ 1 to 0

In H_2SO_4, each oxygen is in the -2 state, hence (-2 x 4) = -8. The sulfur is +6, hence -8 + 6 = -2, so each hydrogen atom is in the +1 state. Elemental hydrogen is produced which is in the 0 oxidation state, hence the oxidation number changes from +1 to 0.

(Total 11 marks)

This question is about properties of the halogens and halide ions.

(a) Bromine can be extracted by bubbling chlorine gas through concentrated solutions containing bromide ions.

(i) Write the electron configuration of a bromide ion, in terms of sub-shells. **[1]**

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$

The question asks for the electronic configuration of the bromide ion, not the bromine atom, so there are a total of 36 electrons, not 35.

(ii) Write an ionic equation for this reaction and state why this reaction takes place in terms of reactivity of the halogens. **[2]**

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

Chlorine is more reactive than bromine and is a stronger oxidising agent.

The oxidation number of *Cl* changes from 0 to –1 and Br changes from –1 to 0, so the bromide ions have been oxidised by the chlorine. Group 7 reactivity increases as you move up the group. Chlorine lies above bromine and is thus able to oxidise it.

(b) Chlorine is used in water treatment.

State **one** benefit and **one** risk of chlorine in water treatment. **[1]**

Benefits: kills **OR** removes bacteria as chlorine is an efficient disinfectant that kills most germs and pathogens.

AND

Risk: toxic / poisonous **OR** forms chlorinated hydrocarbons **OR** forms carcinogens / toxic compounds. These compounds are thermally stable and can remain in the environment during long periods of time. They can also be volatile and evaporate with water into the atmosphere.

Both benefits and risks are required for the mark.

(c) Precipitation reactions can be used to distinguish between halide ions.

(i) State the reagent needed for these precipitation reactions.

[1]

Silver nitrate **OR** $AgNO_3$

(ii) How would the appearance of the precipitates allow you to distinguish between chloride, bromide and iodide ions? **[1]**

Chloride: white (precipitate)

AND Bromide: cream (precipitate)

AND iodide: yellow (precipitate)

Silver chloride is **white**, silver bromide is **cream** and silver iodide is **yellow**.

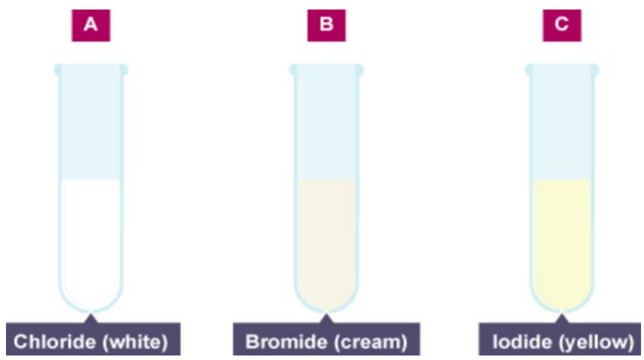


Image showing the colours of the halide ion precipitates, Ag-X

(Total 6 marks)

Aqueous lead(II) nitrate, $Pb(NO_3)_2(aq)$, and aqueous potassium iodide, KI(aq), react together. The equation is shown below.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

A student carries out an experiment to determine the enthalpy change of reaction, $\Delta_r H$, of this reaction.

The student follows the method outlined below.

- Add 50.0 cm^3 of 1.50 mol dm^{-3} $Pb(NO_3)_2(aq)$ to a polystyrene cup.
- Measure out 50.0 cm^3 of a solution of KI(aq), which is in excess.
- Measure the temperature of both solutions.
- Add the KI(aq) to the polystyrene cup, stir the mixture and record the maximum temperature.

Temperature readings

Initial temperature of both solutions = 19.5°C
Maximum temperature of mixture = 30.0°C

(a) Calculate $\Delta_r H$, in kJ mol^{-1}, for the reaction shown in the equation above.

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

Assume that the density of all solutions and specific heat capacity, *c*, of the reaction mixture is the same as for water.

-58.5 kJ mol^{-1}

[4]

Step	**Working out**
1.Use $Q = mc\Delta T$ to calculate the energy released in J or kJ.	$Q = 100.0 \times 4.18 \times 10.5 = 4389$ J **OR** 4.389 kJ
2.Calculate the moles of $Pb(NO_3)_2$	$n(Pb(NO_3)_2) = 1.50 \times \frac{50}{1000} = 0.075(0)$
3.Divide the kJ calculated in step 1 by the moles calculated in step 2 as the question asks you give the answer in kJ mol^{-1}.	$\Delta H = -\frac{4.389}{0.0750} = -58.52 = -58.5$ kJ mol^{-1} correct to three significant figures

(b) Write an ionic equation for the reaction that the student carries out.

Include state symbols. **[1]**

$Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$

Step	Working Out
1. Write out the balanced equation.	$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$
2. Write down the complete ionic equation (the state symbols can be ignored in this step). Note that PbI_2 is an insoluble solid hence it doesn't form ions.	$Pb^{2+} + 2NO_3^{-} + 2K^{+} + 2I^{-} \rightarrow PbI_2 + 2K^{+} + 2NO_3^{-}$
3. Eliminate the spectator ions (underlined, these are the ions that do not participate in the reaction and have the same formula, number, state and charge on either side).	$Pb^{2+} + \underline{2NO_3^{-}} + \underline{2K^{+}} + 2I^{-} \rightarrow PbI_2 + \underline{2K^{+}} + \underline{2NO_3^{-}}$
4. Check that the charges and numbers balance and include the state symbols.	$Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$

(c) The 50.0 cm^3 of KI(aq) used in the experiment contains 10% more KI than is needed to react with 50.0 cm^3 of 1.50 mol dm^{-3} $Pb(NO_3)_2(aq)$.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

Calculate the concentration, in mol dm^{-3}, of KI that the student used. **[2]**

3.3 mol dm^{-3}

Step	Working out
1.Calculate the moles of KI used remembering that the molar ratio of KI : Pb is 2 : 1.	*n*(KI) = 2 x 0.0750 = 0.150 moles
2.Convert to concentration.	[KI] = 0.150 x $\frac{1000}{50}$ = 3 mol dm^{-3}
3.Increase by 10% to find the concentration of KI used.	3 x 1.1 = 3.3 mol dm^{-3}

(Total 7 marks)

Sulfur trioxide, SO_3, is used for the industrial manufacture of sulfuric acid.

SO_3 is produced by reacting sulfur dioxide, SO_2, and oxygen, O_2, as shown in **equilibrium 25.1** below.

Equilibrium 25.1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -197\,kJ\,mol^{-1}$

(a) Le Chatelier's principle can be used to predict how different conditions affect the equilibrium position.

- Using le Chatelier's principle, show that a low temperature and a high pressure should be used to obtain a maximum **equilibrium** yield of SO_3.
- Explain why the actual conditions used in industry may be different from the conditions needed for a maximum equilibrium yield.

[5]

Le Chatelier's Principle states that for a system at equilibrium, the position of the equilibrium changes to minimise the effect of any imposed change in conditions.

Temperature:

(Forward) reaction is exothermic/ΔH is negative **OR** (Forward) reaction gives out heat so at higher temperatures there is an increase in the amount of products. The system compensates by shifting towards the reverse reaction, thus favoring the **reactants**.

Pressure:

Right-hand side has fewer (gaseous) moles **OR** 3 (gaseous) moles form 2 (gaseous) moles so as pressure is increased the equilibrium will shift to the right to decrease the pressure, thus favoring the **products**.

Equilibrium shift

Correct equilibrium shift in terms of **temperature**

Correct equilibrium shift in terms of **pressure**

INDUSTRIAL CONDITIONS

Low temperature gives a slow rate/slower reaction **OR** high temperatures needed to increase rate. This depends on the desired rate of production as well as the economic factors. A slower rate of reaction at a lower temperature may be more preferable to a higher rate at a higher temperature, particularly rate at the higher temperature is not significantly improved. Usually a compromise is made between an acceptable rate of reaction and temperature.

(High) pressure provides a safety risk **OR** (High) pressure is expensive (to generate) / uses a lot of energy. This is another compromise which is made between safety and economic issues involved in maintaining high pressure vessels, tubing etc. and an acceptable rate of production.

(b) Under certain conditions, K_c for **equilibrium 25.1** is 0.160 $dm^3 mol^{-1}$.

The equilibrium mixture under these conditions has the following concentrations of SO_2 and O_2.

Species	**Equilibrium concentration / $mol\,dm^{-3}$**
SO_2	2.00
O_2	1.20

- Using the value of K_c, explain whether the equilibrium position will be towards the right or towards the left under these conditions.
- Calculate the concentration of SO_3 in the equilibrium mixture.

[4]

Value of K_c is small **OR** <1 **AND** equilibrium (position) is towards the left.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

The value of K_c gives an idea of the **proportions** of reactants and products at equilibrium. A value of 1 tells us that the equilibrium lies halfway between reactants and products. Values above 1 favor the products and below 1 favor the reactants. Since the K_c for Equilibrium 25.1 is less than 1, then the equilibrium lies on the left and therefore favors the reactants.

$K_c = \frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ OR $\frac{[SO_3]^2}{2.00^2\ x\ 1.20}$

$K_c = [SO_2]^2[O_2]$

$K_c = 0.160 \times 2.00^2 \times 1.20$

$K_c = 0.768$

Rearrange the equation of K_c for $[SO_3]^2$ and calculate the square root to find the value of $[SO_3]$.

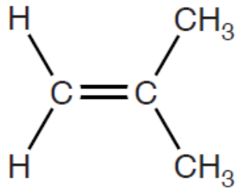
$[SO_3] = \surd\ K_c \times [SO_2]^2 \times [1.20]$

$[SO_3] = \surd\ (0.160) \times (2.00)^2 \times (1.20)$

$[SO_3] = 0.876\ mol\ dm^{-3}$

(Total 9 marks)

Compound **B**, shown below, can be used to synthesise organic compounds with different functional groups.



Compound B

(a) **(i)** Compound **B** is a member of a homologous series.

Name the homologous series and state its general formula.

Homologous series ....Alkene........

General formula ....C_nH_{2n}........ **[1]**

If unsure about the general formula you can always substitute the numbers from the given molecule and check that the formula gives the correct amount of C and H atoms.

(ii) What reagents and conditions are needed to convert compound **B** into a saturated hydrocarbon? **[1]**

Hydrogen/H_2 AND Ni (catalyst)

In hydrogenation reactions, alkenes are converted to alkanes through the addition of **hydrogen** across the double bonds via π bond rupture. The reaction occurs at high temperatures (around 425K) and pressures, and a **nickel** catalyst is used. Platinum, palladium or rhodium could also be used.

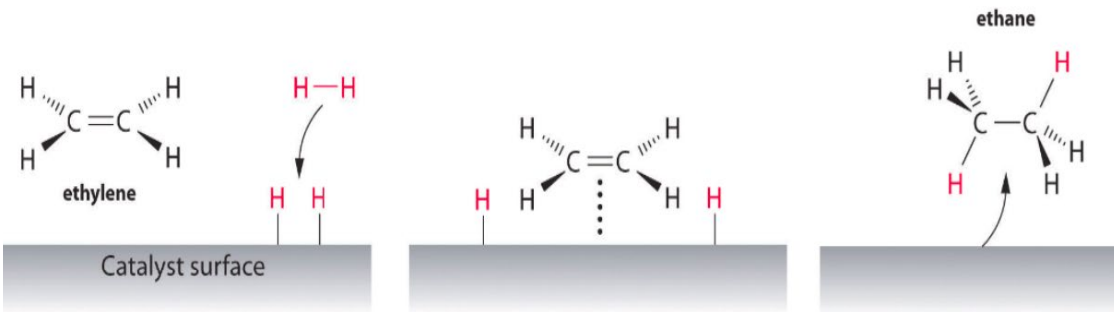
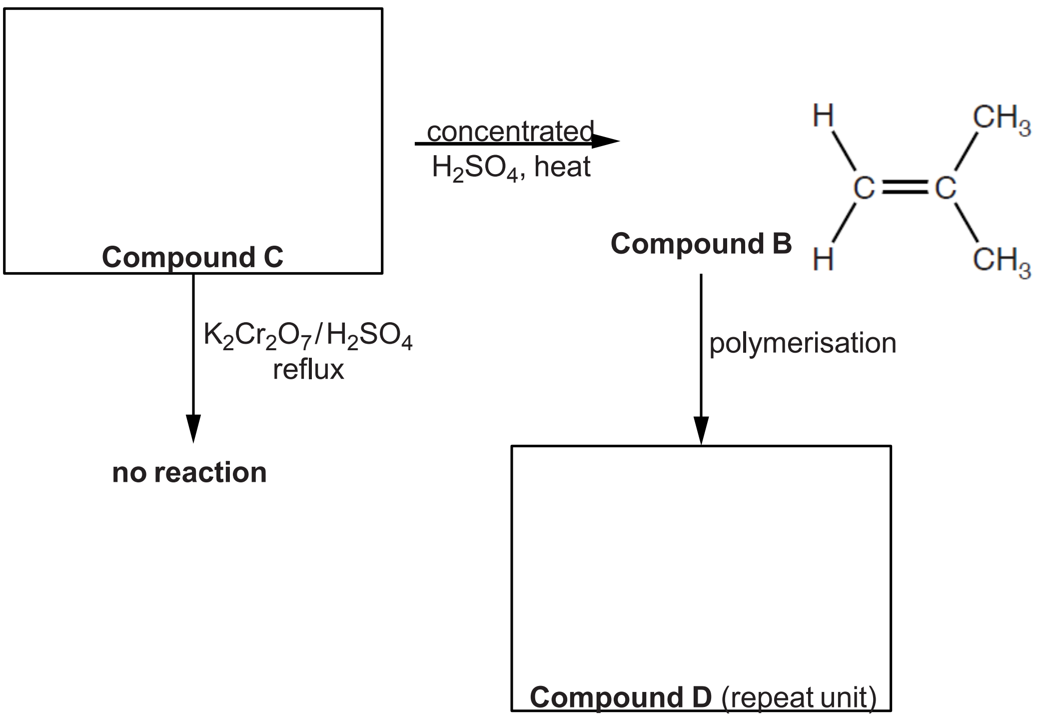


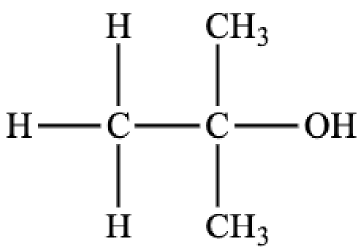
Image showing the catalytic hydrogenation of ethene (ethylene) to ethane

(b) Some reactions involving compound **B** are shown in the flowchart below.

Complete the flowchart, showing the structures of organic compounds **C** and **D**.



[2]



Compound C is a **tertiary alcohol** which do not undergo oxidation reactions, hence there is no reaction with acidified potassium dichromate. Alcohols are dehydrated by heating under reflux in concentrated acidic catalytic conditions which produces an alkene.

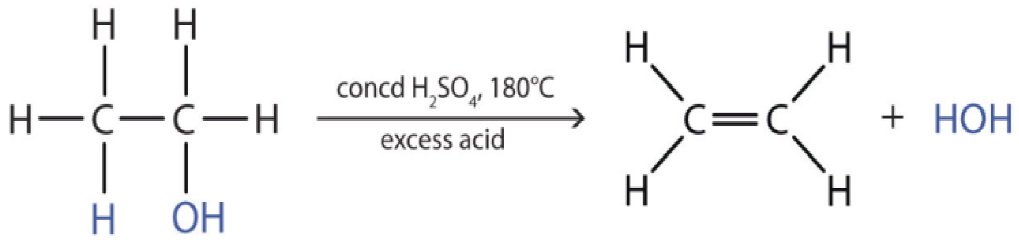
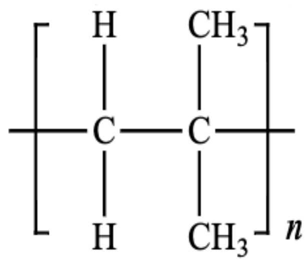


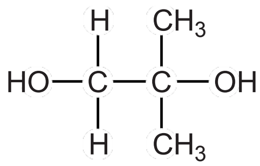
Image showing the dehydration of ethanol producing ethene and a water molecule



Alkenes undergo polymerisation reactions which are shown using notation as shown in compound D. When drawing the repeat units make sure you:

- Replace the C=C with a single bond and add on the side atoms / groups correctly.
- Add the square brackets and the continuation bonds which **extend** through the brackets on either side.
- Add small subscript n on the right hand side which indicates there is a large number of repeat units.

(c) The structure of compound **F** is shown below.



Compound F

(i) What is the empirical formula of compound **F**? **[1]**

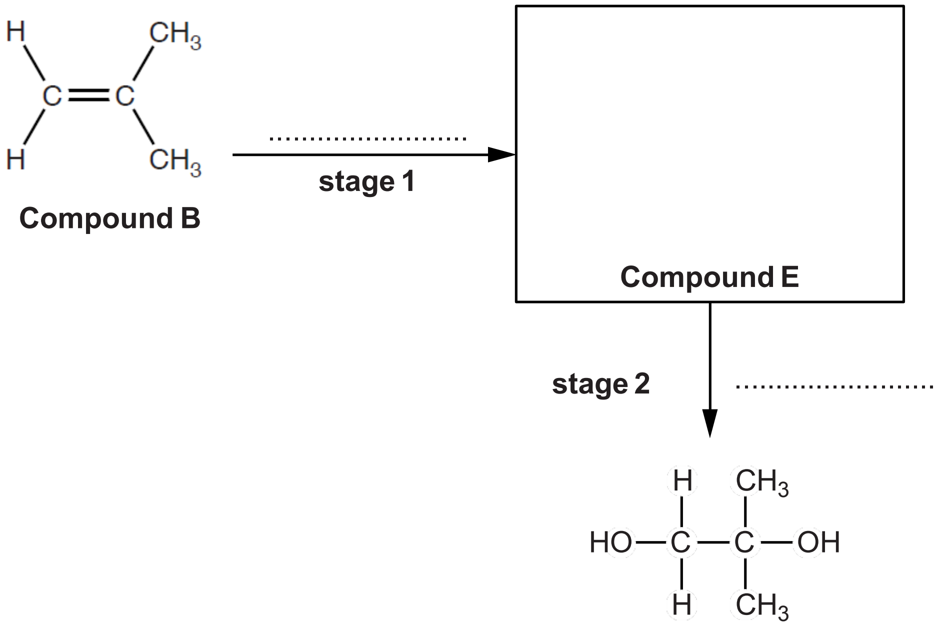
C_2H_5O

Count the number of C, H and O atoms to get the **molecular formula**, $C_4H_{10}O_2$. Then divide across by 2 to find the lowest whole number ratio which is the **empirical formula**.

(ii) A student plans a two-stage synthesis for preparing compound **F** from compound **B.**

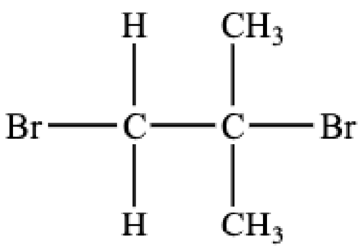
The synthesis first prepares compound **E**, as shown in the flowchart.

Draw the structure of compound **E** in the box and state the reagents for each stage on the dotted lines.



Compound F

[3]



Stage 1: Compound E: Bromine/Br_2

Halogenation of alkenes involves the rapid addition of halogen across the C=C double bond which occurs at room temperature.

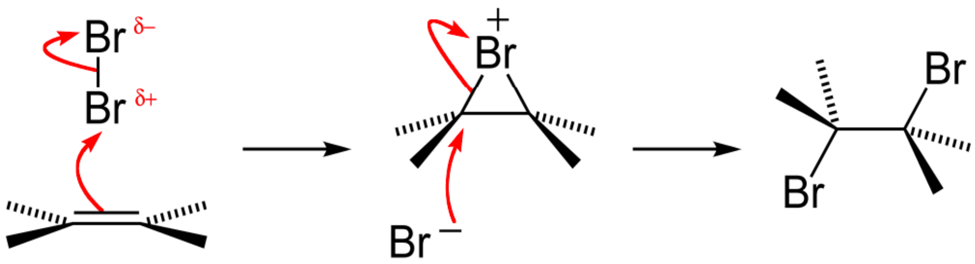


Image showing the mechanism for the bromination of ethene

Stage 2: NaOH/KOH **OR** OH^- Only award if intermediate contains at least one halogen atom

Compound E is a haloalkane which undergoes hydrolysis via a nucleophilic substitution reaction. The halogen atoms are replaced by the nucleophilic OH^- groups. Alcohols are formed in this process which is performed at high temperatures and under reflux.

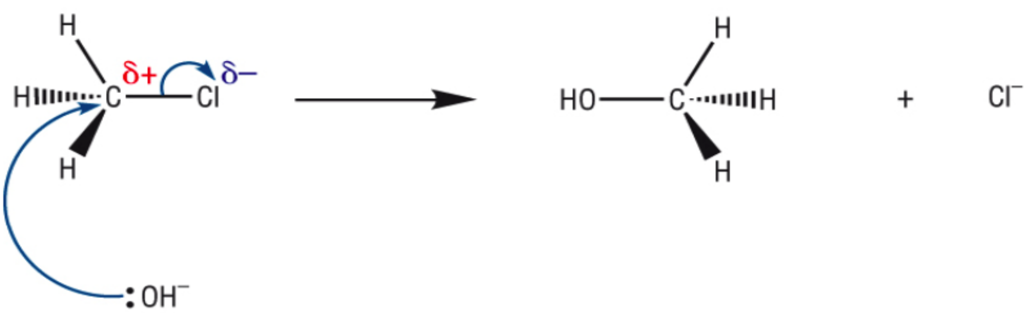


Image showing the nucleophilic substitution mechanism for the hydrolysis of chloromethane

(Total 8 marks)