H032/02
Depth in Chemistry
Specimen Paper

Model Answers

Level	AS Level
Subject	Chemistry A
Exam Board	OCR
Paper Code	H032/02
Paper	Depth 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%

Bromine is a reactive element. It combines with other non-metals to form covalent compounds. Phosphorus tribromide, PBr_3, and iodine monobromide, IBr, are examples of covalent compounds used in organic synthesis.

(a) PBr_3 can be prepared by heating bromine with phosphorus, P_4.

(i) Write an equation for this reaction. **[1]**

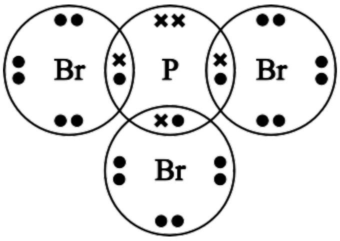
$P_4 + 6Br_2 \rightarrow 4PBr_3$

PBr_3 is used extensively in the conversion of primary or secondary alcohols to alkyl bromides.

(ii) How many molecules are present in 1.3535 g of PBr_3? **[3]**

Step	**Working out**
1. Calculate the M_r of PBr_3.	M_r PBr3 = 31 + (3 x 79.9) = 270.7
2. Multiply the M_r by the amount in grams given in the question to convert to moles.	$n(PBr_3) = \frac{1.3535}{270.7} = 5.000 \times 10^{-3}$ mol
3. Multiply by Avogadro's constant to calculate the number of molecules.	Number of molecules = $(5.000 \times 10^{-3}) \times (6.023 \times 10^{23}) = 3.01 \times 10^{21}$

(iii) The '*dot-and-cross*' diagram of a molecule of PBr_3 is given below.



[3]

Name the shape of this molecule and explain why the molecule has this shape.

name:

explanation:

The shape of PBr_3 is Pyramidal (because there are) 3 bonded pairs and 1 lone pair (around the central phosphorus atom). Electron pairs repel each other as far apart as possible so will take on a tetrahedral arrangement (giving a pyramidal shape overall).

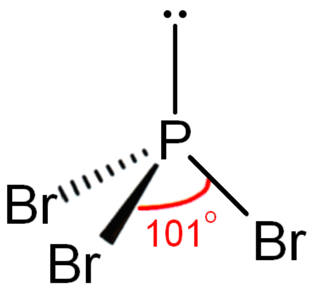


Image showing the pyramidal shape of PBr_3 as the lone pair exerts repulsion from above

(b) Bromine reacts with iodine to form iodine monobromide, IBr.

The table below lists some average bond enthalpies which are required in different parts of this question.

Bond	**Average bond enthalpy / kJ mol^{-1}**
Br–Br	+193
I–I	+151
I–Br	+175

(i) Average bond enthalpy is the enthalpy change for the breaking of 1 mole of bonds in gaseous molecules.

Why do Br_2 and I_2 **not** exist in the gaseous state under standard conditions? **[1]**

This is (because energy is needed to break) induced dipole– dipole interactions / London forces between molecules, which causes them to cling together more than fluorine or chlorine. Boiling points increase moving down the Group VII elements due to increasing numbers of electrons in the atoms.

(ii) Calculate the enthalpy change of formation, $\Delta_f H$, for IBr. **[2]**

Step	**Working out**
1. Calculate the enthalpies of bond breaking.	Bond breaking (+193) + (+151) = (+)344
2. Calculate the enthalpies of bond making.	Bond making 2 x (-175) = (-)350
3. Add together and divide by 2 to calculate the $\Delta_f H$ for IBr (divide by 2 as 2 moles of IBr are produced).	$Br_2 + I_2 \rightarrow 2IBr$ $\Delta_f H = \frac{(+344) + (-350)}{2}$ = -3 (kJ mol^{-1})

(c) Iodine monobromide, I–Br, is a polar molecule.

Heterolytic fission of the I–Br bond forms an electrophile.

State the meaning of the term *electrophile* and suggest the formula of the electrophile formed from IBr.

[2]

Electron pair acceptor

An electrophile is an atom or a group of atoms that is attracted to an electron-rich area and accepts an electron pair.

I^+

Electrophiles are usually positive ions or molecules which also contain an atom with a partial positive charge ($\delta+$).

(d) Bromine disproportionates when it reacts with potassium hydroxide solution.

Suggest an equation for this reaction. **[1]**

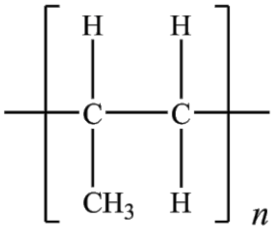
$Br_2 + 2KOH \rightarrow KBr + KBrO + H_2O$

Disproportionation reactions involve oxidation **and** reduction of the same species in a reaction. Bromine has been reduced on going from Br_2 to KBr and oxidised on going from Br_2 to KBrO.

A large proportion of the world's output of organic chemicals is used to make addition polymers. These polymers have a variety of uses.

(a) Poly(propene) is used to make packaging, textiles and rope.

A repeat unit for poly(propene) is shown below.



(i) Explain why poly(propene) is a *saturated* hydrocarbon. **[1]**

(Because) molecule contains only single C–C bonds, there are no carbon carbon double or triple bonds present, hence it is saturated.

(ii) State the bond angle around each carbon atom in poly(propene). **[1]**

109.5°

Each carbon atom has four sigma bonds which hybridize giving a tetrahedral shape with bond angles of 109.5°.

(iii) After polymers have been used for packaging, the waste polymers need to be processed to save resources, for example, by recycling.

Describe **two** other ways in which waste poly(propene) can be processed in a sustainable way. **[2]**

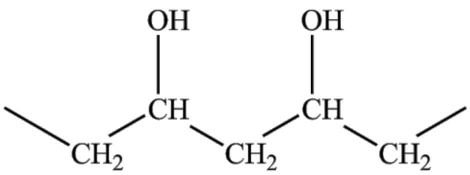
Combustion for energy production (alternative to fossil fuels)

Combustion is an exothermic reaction and the energy can be used to heat water to create steam which can drive turbines to produce electricity.

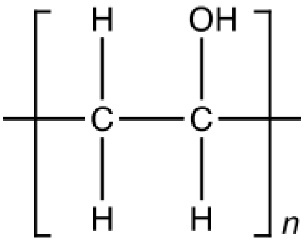
Use as an organic feedstock for large scale production of other materials.

(b) Poly(ethenol) is used to make soluble laundry bags.

A section of the structure of poly(ethenol) is shown below.



(i) Draw a structure to represent one repeat unit of poly(ethenol). **[1]**



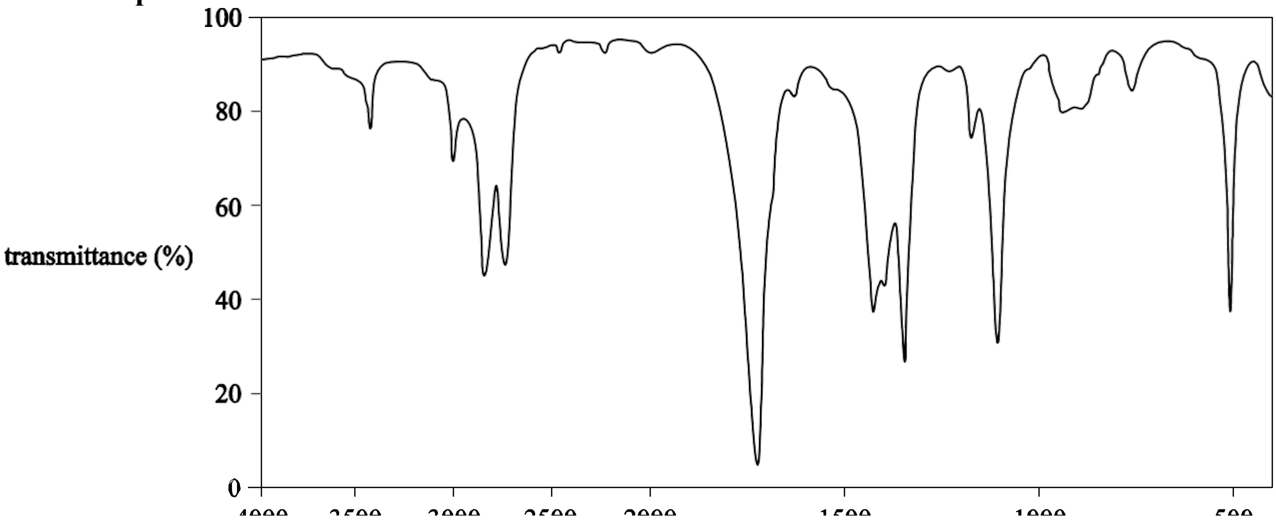
Replace the C=C bond with a C-C bond and maintain the relative positions of the side groups. Extension bonds to come through either side of the brackets and a small subscript n to go on the bottom right hand side.

(ii) Poly(ethenol) is not manufactured from ethenol.

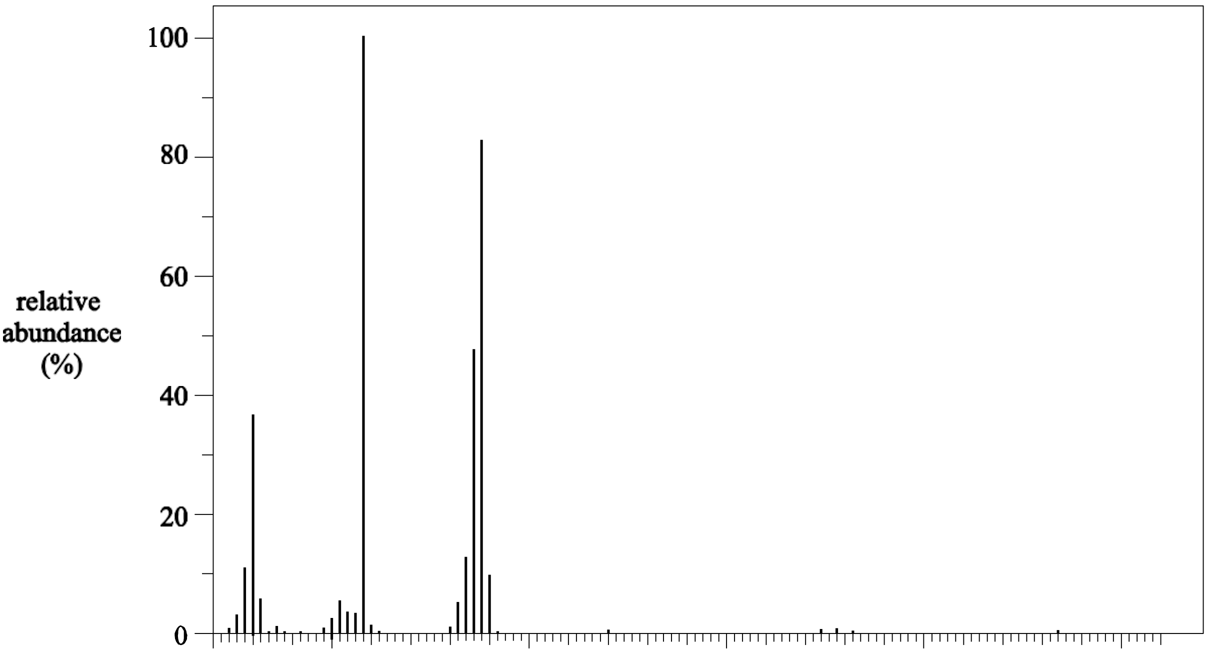
Ethenol is unstable and it forms a more stable structural isomer.

Analysis of the structural isomer gave the following data.

Infrared spectrum



Mass spectrum



Use **all** the data to show that the isomer is **not** ethenol.

Identify the structural isomer of ethenol.

In your answer you should make clear how your explanation is linked to the evidence. **[4]**

Evidence against ethenol:

No infrared absorption between 3200 and 3600 cm^{-1} from O–H which is a crucial part of the puzzle, indicating that the isomer is not even an alcohol.

Evidence for isomer:

Infrared absorption between 1640 and 1750 cm^{-1} indicates C=O

The presence of a C=O bond definitely negates the isomer is ethenol, could be an aldehyde, ester or ketone.

Mass spectrum: fragmentation peak at m/z = 29 suggests CHO^+

OR fragmentation peak at m/z = 15 suggests CH_3

Identification:

Ethanal/CH_3CHO

Ethanal fits with all of the clues and could produce the spectra as seen.

Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

(a) Describe and explain the effect of increasing the pressure on the rate of this reaction. **[2]**

(Increase in pressure) increases the rate **AND** because molecules are closer together…

… so there are more collisions per unit time. From the balanced equation, there are fewer gaseous molecules on the right than on the left, so increasing pressure shifts the **equilibrium** to the right, favouring the products.

(b) A mixture of N_2 and H_2 was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

N_2	1.20 mol dm^{-3}
H_2	2.00 mol dm^{-3}
NH_3	0.877 mol dm^{-3}

(i) Calculate a value for K_c for this equilibrium. **[3]**

Step	**Working out**
1. Write out the expression for K_c.	$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$
2. Input the data as provided in the question.	$K_c = \frac{[0.877]^2}{[2.00]^3[1.20]}$
3. Solve for K_c.	K_c = 0.0801
4. For the units, substitute the expression for concentration into the equation for K_c.	$\frac{(mol\ dm^{-3})(mol\ dm^{-3})}{(mol\ dm^{-3})(mol\ dm^{-3})(mol\ dm^{-3})(\text{m}}$

5. Cancel out as many same terms above and below the line, then bring remaining terms above the line, changing the signs of the exponentials and adding the numbers.	K_c = 0.0801 $dm^6\ mol^{-2}$

(ii) Explain how the following changes would affect the amount of NH_3 present in the equilibrium mixture. **[3]**

Catalyst: No effect, it only changes the rate of reaction and therefore the equilibrium position remains unchanged.

Higher temperature: Forward reaction is exothermic so position of equilibrium moves to the left and there will be less NH_3 as the equilibrium system opposes the change.

(c) 1.00 tonne of ammonia from the Haber process is reacted with carbon dioxide to prepare the fertiliser urea, NH_2CONH_2.

$$2NH_3(g) + CO_2(g) \rightarrow NH_2CONH_2(s) + H_2O(l)$$

1.35 tonnes of urea are formed.

Calculate the percentage yield of urea. **[3]**

Step	Working out
1.Calculate the moles of NH_3.	$n(NH_3) = \frac{1 \times 10^6}{17}$ = 5.88 x 10^4 (58824) (mol)
2.Calculate the theoretical yield of urea in moles.	$n(NH_2CONH_2) = \frac{5.88 \times 10^4}{2}$ = 2.94 x 10^4 (29412) (mol)

3. Calculate the actual yield of urea in moles.	$n(NH_2CONH_2) = \frac{1.35 \ x \ 10^6}{60}$ = 2.25 x 10^4 (22500) (mol)
3. Calculate the percentage yield using the equation: % yield = $\frac{actual \ yield}{theoretical \ yield}$ x 100.	% yield = $\frac{2.94 \ x \ 10^4}{2.25 \ x \ 10^4}$x 100 = 76.5 %

Students work together in groups to identify four different solutions.

Each solution contains one of the following compounds:

- ammonium sulfate, $(NH_4)_2SO_4$
- sodium sulfate, Na_2SO_4
- sodium chloride, NaCl
- potassium bromide, KBr.

Your group has been provided with universal indicator paper and the following test reagents:

- barium chloride solution
- silver nitrate solution
- dilute ammonia solution
- sodium hydroxide solution.

(a)* A student in your group suggests the following plan:

- Add about 1 cm depth of each solution into separate test-tubes.
- Add a few drops of barium chloride solution to each test-tube.
- A white precipitate will show which solutions contain sulfate ions.
- Two of the solutions will form a white precipitate.

Describe how you would expand this plan so that all four solutions could be identified using a positive test result.

You should provide observations and conclusions that would enable your group to identify all four solutions. **[6]**

Details of tests

For anions, the order of tests should be carbonate - sulfate - halides. They are tested for in this order to avoid confusing results which can occur due to multiple ions reacting with the added reagents. Start off with tests to identify sulfates:

- Ammonium ion test: on the sulfates already identified (this is done by the addition of barium chloride which produces (if sulfates are present), the insoluble precipitate $BaSO_4$; warm with NaOH(aq) followed by

Universal indicator test: use of moist indicator paper on (ammonia) gas; correct observation (alkaline gas/high pH/blue or purple) for identification of $(NH_4)_2SO_4$, and by

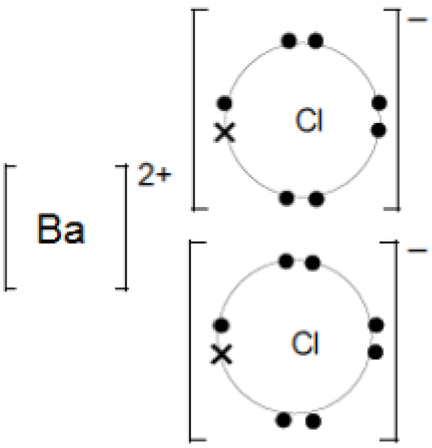
- default of Na_2SO_4 (this will be the one that doesn't cause a colour change as it is a neutral salt).

To identify halides:

- Halide ion test: addition of silver nitrate solution to the remaining two solutions; correct observation (white precipitate - chloride / cream precipitate - bromide) followed by
- Solubility of precipitate: addition of dilute ammonia solution to halide precipitates; correct observation (silver chloride dissolves) enabling identification of NaC*l* and by default of KBr as it is insoluble in dilute ammonia solution.

(b) Solid barium chloride has a high melting point. Barium chloride dissolves in water to form a solution that can be used to test for sulfate ions.

(i) Draw a '*dot-and-cross*' diagram to show the bonding in solid barium chloride. Show outer electrons only. **[2]**



Barium ion with no (or eight) electrons (as it has lost its outer two electrons)

AND two chloride ions with correct dot-and-cross octet.

Correct charges on all species.

(ii) A solution of barium chloride can be made in the laboratory using dilute hydrochloric acid.

Suggest a compound that can be reacted with hydrochloric acid to make barium chloride. **[1]**

Barium hydroxide **OR** barium oxide **OR** barium carbonate

Barium hydroxide:

$$Ba(OH)_2 + 2HCl \rightarrow BaCl_2 + 2H_2O$$

Barium oxide:

$$2BaO + 4HCl \rightarrow 2BaCl_2 + 2H_2O$$

Barium carbonate:

$$BaCO_3 + 2HCl \rightarrow BaCl_2 + H_2O + CO_2$$

Alcohols are used in organic synthesis.

(a) Pentan-2-ol can be prepared by the alkaline hydrolysis of 2-iodopentane.

$$CH_3CH(I)CH_2CH_2CH_3 + NaOH \rightarrow CH_3CH(OH)CH_2CH_2CH_3 + NaI$$

The reaction mixture is boiled for 20 minutes.

(i) State the most appropriate technique that could be used to boil the reaction mixture for 20 minutes. **[1]**

Reflux is used to obtain a higher yield.

(ii) Describe the mechanism for the alkaline hydrolysis of 2-iodopentane.

In your answer, include the name of the mechanism, curly arrows and relevant dipoles. **[4]**

name of mechanism: ....

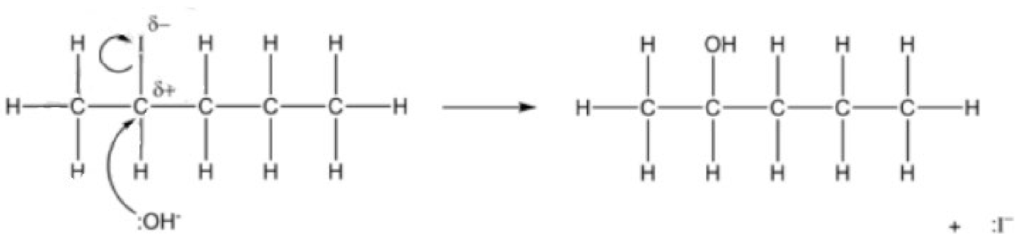
This is a nucleophilic substitution reaction.

Mechanism

Curly arrow from lone pair on OH^- to δ^+ carbon atom

Curly arrow and dipole on C–I bond

Correct products: draw the structure of the alcohol and also the displaced iodine.



Exam Tip

Curly arrows must be drawn clearly and accurately and should always start at either the bond or electron lone pair. The head of the arrow always goes at the atom to which the electron pair transfers.

(b) Alcohols can be converted into haloalkanes in a substitution reaction.

Plan an experiment to prepare approximately 0.1 mol of 2-bromopentane, $CH_3CHBrCH_2CH_2CH_3$, from pentan-2-ol, $CH_3CH(OH)CH_2CH_2CH_3$.

Your plan should include a calculation of the mass of alcohol required and details of the chemicals to be used in the reaction. **[2]**

The minimum of *n*(pentan-2-ol) required = 0.1 × 88 = 8.8 g. React the alcohol with a mixture of NaBr **AND** H_2SO_4 AND warm (to distil off the product).

These reactions are best carried out under reflux.

(c)* Alcohols can be converted into alkenes in an elimination reaction.

The elimination of H_2O from pentan-2-ol forms a mixture of organic products.

Give the names and structures of all the organic products in the mixture.

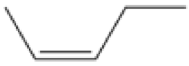
Your answer should explain how the reaction leads to the different isomers. **[6]**

Indicative scientific points may include:

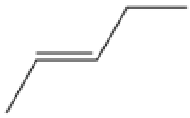
- the elimination can produce a double bond in either the 1- or the 2- position (through combination of the hydroxyl group with a hydrogen from either the 1st or the 3rd carbon)
- this leads to the formation of structural isomers (pent-1-ene and pent-2-ene)
- pent-2-ene exhibits stereoisomerism / E/Z isomerism / cis–trans isomerism because it has two different groups attached to each carbon atom but pent-1-ene does not.
- there are two possible isomers of pent-2-ene and three in total

Names and structures of alkenes

pent-1-ene



Z or *cis*-pent-2-ene



E or *trans*-pent-2-ene

A student carries out an experiment to identify an unknown carbonate.

- The student weighs a sample of the solid carbonate in a weighing bottle.
- The student tips the carbonate into a beaker and weighs the empty weighing bottle.
- The student prepares a 250.0 cm^3 solution of the carbonate.
- The student carries out a titration using 25.0 cm^3 of this solution measured using a pipette with 0.100 mol dm^{-3} hydrochloric acid in the burette.

(a) The sample of carbonate is dissolved in approximately 100 cm^3 of distilled water in a beaker and the solution transferred to a volumetric flask. The volume of the solution is made up to 250.0 cm^3 with distilled water.

Another student suggests two possible sources of error:
- A small amount of solid remained in the weighing bottle.
- A small amount of solution remained in the beaker.

State whether the other student's statements are correct.

How could the procedure be improved? **[2]**

Not correct about the solid remaining in the weighing bottle (weighed by difference) as the student calculated the mass transferred by weighing before and after the transfer of the solid to the beaker.

AND

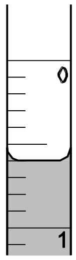
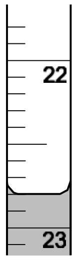
Correct about the solution in the beaker as volumetric glassware should be used for quantitative analysis.

Rinse out the beaker with distilled water and transfer to the volumetric flask **before** making up to 250 cm^3

(b) The student carries out the final part of the experiment by adding 0.100 mol dm^{-3} hydrochloric acid to a burette and performing a titration using a 25.0 cm^3 sample of the aqueous carbonate.

The student reads the burette to the nearest 0.05 cm^3.

The diagrams below show the initial burette reading and the final burette reading.

initial reading		final reading	

(i) Record the student's readings and the titre. **[1]**

Initial reading = 0.60 (cm^3)

Final reading = 22.80 (cm^3)

Titre = 22.20 cm^3

Initial and final values recorded to two decimal places **AND** titre recorded to the nearest

0.05 cm^3 with correct units

Carefully note the readings, using a ruler if it helps you to read more clearly the numbers

from

the diagram. The readings are taken from a burette, hence the volume increases downwards

and not upwards.

(ii) Describe what the student should do next to obtain reliable results for the titration. **[1]**

Suggests repeating the titration to obtain consistent/concordant results

(those that agree to within 0.1 cm^3) **AND** calculating the mean titre as the

first titration serves to find the rough titre.

(c) The equation below represents the reaction between the carbonate and hydrochloric acid.

$$M_2CO_3(aq) + 2HCl(aq) \rightarrow 2MCl(aq) + CO_2(g) + H_2O(l)$$

(i) Calculate the amount, in mol, of M_2CO_3 used in the titration. **[2]**

Step	Working out
1.Calculate the moles of HC*l*.	$n(HCl) = \frac{(0.100)(22.20)}{1000} = 0.00222$ (mol)
2.Calculate the moles of M_2CO_3.	$n(M_2CO_3) = \frac{0.00222}{2} = 0.00111$ (mol)

(ii) The student's mass readings are recorded below.

Mass of weighing bottle + carbonate / g	14.92
Mass of weighing bottle / g	13.34

Use the student's results to identify the carbonate, M_2CO_3. **[4]**

Step	Working out
1.Calculate the moles of M_2CO_3.	$n(M_2CO_3) = 0.00111 \times 10 = 0.0111$ mol
2.Calculate the molar mass of the solid.	Mass used 14.92 - 13.34 = 1.58 g Molar mass = $\frac{1.58}{0.0111}$ = 142.3 g mol^{-1}
3. Subtract mass of CO_3 to find mass of M.	Mass M = $\frac{142.3 - 60}{2}$ = 41.15 (= K, potassium)
4. Write out the formula for the compound.	K_2CO_3 Note: molar mass is between K_2CO_3 (138.2) and $SrCO_3$ (147.6); only possible match for a Group 1 carbonate is K_2CO_3.

Question 7

An alcohol **A** contains carbon, hydrogen and oxygen only. The alcohol is a liquid at room temperature and pressure but can easily be vaporised.

1.15 g of **A** produces 761 cm^3 of gas when vaporised, measured at 100 kPa and 366 K.

Determine the molar mass of compound **A** and draw a possible structure for **A**. **[5]**

Step	Working out
1.Rearrange the gas equation for *n*.	$pV = nRT$ $n = \frac{pV}{RT}$
2.Check the units and convert if necessary.	Volume conversion: 761 cm^3 = 761 x 10^{-6} m^3 Pressure: 100 kPa = 100 x 10^3 Pa
3. Substitute the values into the equation.	$n = \frac{(100 \; x \; 10^3)(761 \; x \; 10^{-6})}{8.314 \; x \; 366}$ n = 0.0250 mol
4. Calculate the relative atomic mass by dividing the mass given in the question by the moles calculated in step 3.	$M = \frac{m}{n}$ $M = \frac{1.15}{0.0250}$ = 46.0 (g mol^{-1})
5. 2 x C = 24, 1 x O = 16, 6 x H = 6, which gives a total of 46, so a possible structure would be CH_3CH_2OH.