OCR
Oxford Cambridge and RSA

Monday 19 June 2023 – Afternoon

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Advance Notice Article

Time allowed: 2 hours 15 minutes

696O1O8186

INSTRUCTIONS
- Do **not** send this Advance Notice Article for marking. Keep it in the centre or recycle it.

INFORMATION
- This is a clean copy of the Advance Notice Article you have already seen.
- This document has **4** pages.

Calcium Carbide

Adapted from: Group 14 (C, Si, Ge, Sn, and Pb) Alkaline Earth Compounds by R.C. Ropp, in Encyclopedia of the Alkaline Earth Compounds, 2013, Elsevier

Calcium carbide has the nominal formula of CaC_2 and the molecular weight of 64.0992 g / mol. The pure material is colorless, but most samples have a color ranging from black to greyish-white, depending on the grade. Its density is 2.22 g / cc and it melts at 2160 °C with a boiling point (under an inert atmosphere) of 2300 °C, where it decomposes. Its main use industrially is in the production of acetylene (ethyne) and calcium cyanamide, $CaCN_2$. Calcium carbide is produced industrially in an electric-arc furnace from a mixture of $CaCO_3$ and coke (carbon) at approximately 2000 °C. This method has not changed since its invention in 1888:

$$CaCO_3 + 3C \rightarrow CaC_2 + CO + CO_2$$

The high temperature required for this reaction is not practically achievable by traditional combustion, so the reaction is performed in an electric-arc furnace where the electrodes are graphite. The carbide product produced generally contains around 80–85% calcium carbide by weight. The carbide is crushed to produce small lumps that can range from a few millimeters up to 50 mm. The impurities are concentrated in the finer fractions. The CaC_2 content of the product is assayed by measuring the amount of acetylene produced on hydrolysis. As an example, the U.S. standard for the content of the coarser fractions is 295–300 l / kg. Impurities present in the carbide include phosphide, which produces PH_3 (a poisonous gas) when the CaC_2 is hydrolyzed to produce HC≡CH , i.e. acetylene.

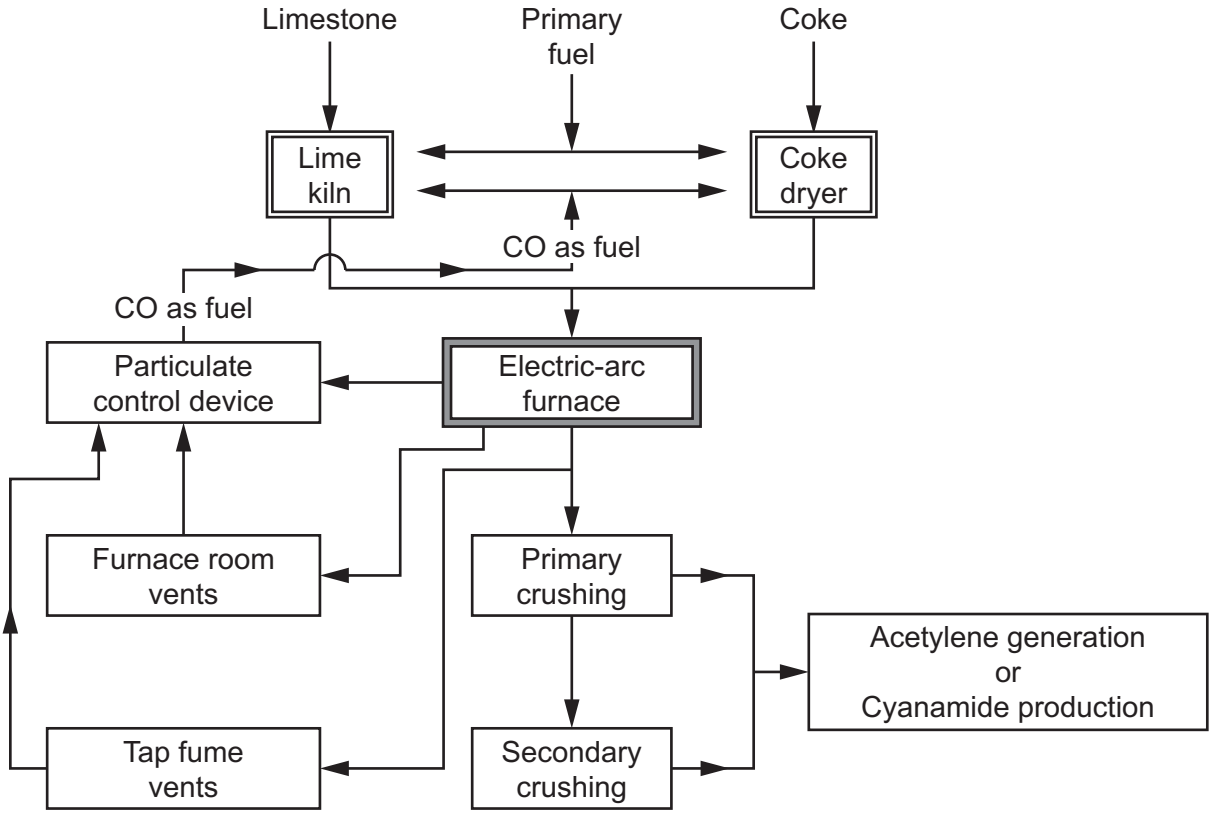
This reaction was an important part of the industrial revolution in chemistry, and was made possible in the U.S. as a product of massive amounts of cheap hydroelectric power generated at Niagara Falls before the turn of the twentieth century. The method for the production of CaC_2 in an electric-arc furnace was discovered independently by two researchers in Europe in 1888 and 1892. **Fig. 1** is an illustration of how CaC_2 has been manufactured.

The common crystalline form at room temperature is a distorted rock salt structure with the C_2^{2-} units lying parallel. In calcium carbide, CaC_2, the C≡C triple bond length is about 1.092 Å (similar to ethyne).

This reaction is the basis of the industrial manufacture of acetylene, and is the major industrial use of calcium carbide in industrial circles:

$$CaC_2 + 2H_2O \rightarrow HC{\equiv}CH + Ca(OH)_2$$

Fig. 1 Industrial Process for Producing Calcium Carbide



In China, acetylene derived from calcium carbide remains a raw material for their chemical industry, in particular for the production of polyvinyl chloride. Locally produced acetylene is more economical than using imported oil. Production of calcium carbide in China has been increasing. In 2005, output was 8.94 million tons, with the capacity to produce 17 million tons. In the USA, Europe and Japan consumption is generally declining. Production levels in the USA in the 1990s were 236 000 tons per year.

Calcium carbide reacts with nitrogen at high temperature to form calcium cyanamide:

$CaC_2 + N_2 \rightarrow CaCN_2 + C$

Calcium cyanamide is used as fertilizer. It is hydrolyzed to cyanamide, $H_2N–C{\equiv}N$, in the soil and is readily available to plants as a nitrogen plant food.

Calcium carbide was used in carbide lamps, in which water drips on the carbide and the acetylene formed is ignited. These lamps were usable but dangerous in coal mines, where the presence of the flammable gas methane made them a serious hazard. The presence of flammable gases in coal mines led to the miner “safety lamp”. However, carbide lamps were used extensively in slate, copper and tin mines, where methane is less likely, but most have now been replaced by electric lamps. They were also used extensively as headlights in early automobiles, motorcycles and bicycles, although in this application they are also obsolete, having been replaced entirely by electric lamps, and in some cases, by LED lamps.

END OF ADVANCE NOTICE ARTICLE

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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 | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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 **24** pages.

ADVICE
- Read each question carefully before you start your answer.

1 The element bromine is extracted from seawater.

Bromide ions are present in seawater in very low concentrations compared with chloride ions.

(a) (i) Excess chlorine is added to acidified seawater, forming aqueous bromine.

Write an **ionic** equation for the reaction of chlorine with bromide ions and explain how it shows that chlorine is more reactive than bromine.

Equation:

Explanation: .....

.....

[2]

(ii) Air is blown through the mixture to remove the bromine as a vapour.

Sulfur dioxide is then added, and the mixture is dissolved in water.

Bromine reacts to form concentrated HBr.

$Br_2(aq) + SO_2(aq) + 2H_2O(l) \rightarrow 2HBr(aq) + H_2SO_4(aq)$

What is the oxidising agent in this reaction?

Explain your answer using oxidation states.

.....

.....

.....

..... **[2]**

(iii) Concentrated Br_2 is made from the concentrated HBr by displacement using chlorine.

Complete the table to give the properties of chlorine, bromine and iodine.

Halogen	Colour at room temperature	Physical state at room temperature
chlorine		
bromine		
iodine		

[2]

(b) Some of the hazards of transporting bromine are similar to those of transporting chlorine.

Suggest **two** hazards of transporting bromine in a road tanker.

Hazard 1 .....

.....

Hazard 2 .....

.....

[2]

(c) Some students add aqueous silver nitrate to a sample of seawater.

They expect to see a cream precipitate of silver bromide but the precipitate is pure white.

(i) Write an **ionic** equation for the reaction of silver ions with **bromide** ions.

Show state symbols.

[2]

(ii) Suggest why the students do **not** get the result they expect.

.....

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..... **[2]**

(d) The students titrate 25.0 cm^3 of a solution of bromine with sodium thiosulfate in the presence of excess iodide ions.

$Br_2 + 2I^- \rightarrow 2Br^- + I_2$

$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$

They find that 24.65 cm^3 of 0.380 mol dm^{-3} sodium thiosulfate is required to reach the end point.

Calculate the concentration of Br_2 in mol dm^{-3}.

concentration = ... mol dm^{-3} **[2]**

(e) The students have another solution containing 20 g dm^{-3} bromine.

They find that 160 cm^3 of this solution reacts exactly with 0.80 g of a hydrocarbon with a molecular formula of C_6H_8.

Suggest a structure for the hydrocarbon.

[4]

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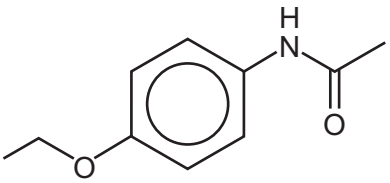
Turn over for the next question

2 Phenacetin was used as a pain-relieving medicine until its harmful side-effects were discovered.



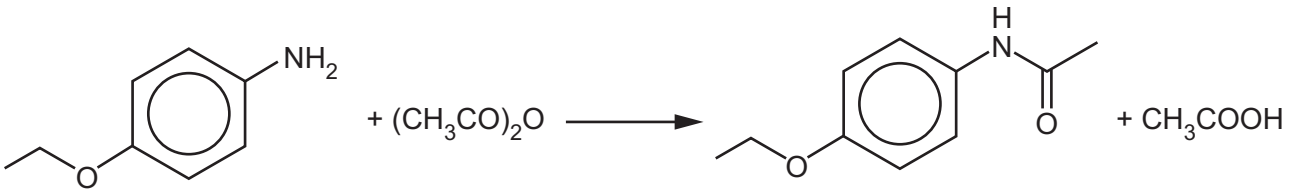
Phenacetin

(a) Phenacetin has a secondary amide group attached to a benzene ring. It also has one other functional group.

Name this functional group.

..... **[1]**

(b) Some students set out to make phenacetin from compound **A**, using the reaction shown.



Compound A **Compound B** **Phenacetin (M_r = 179)**

(i) Give the systematic name of compound **B**.

..... **[1]**

(ii) The students use 14 g of both compound **A** and compound **B**.

Calculate the amounts of each (in mol) that show that compound **B** is in excess.

amount of compound **A** = ... mol

amount of compound **B** = ... mol
[2]

(iii) The students recrystallise their crude phenacetin using water and obtain 20 g of solid product. They calculate their percentage yield.

What advice would you give them?

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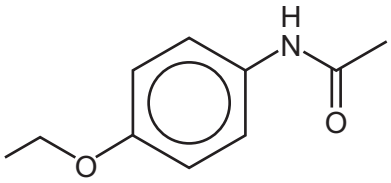
..... **[3]**

(c) The students boil some phenacetin with aqueous acid.



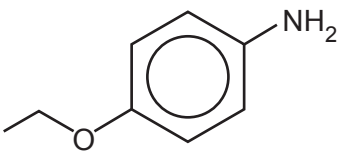
Phenacetin

Draw the structures of the **two** products formed in the boxes below.

[2]

(d) Compound **A** reacts with propanoyl chloride.

Draw the **skeletal** formula of the organic compound formed in the box below.

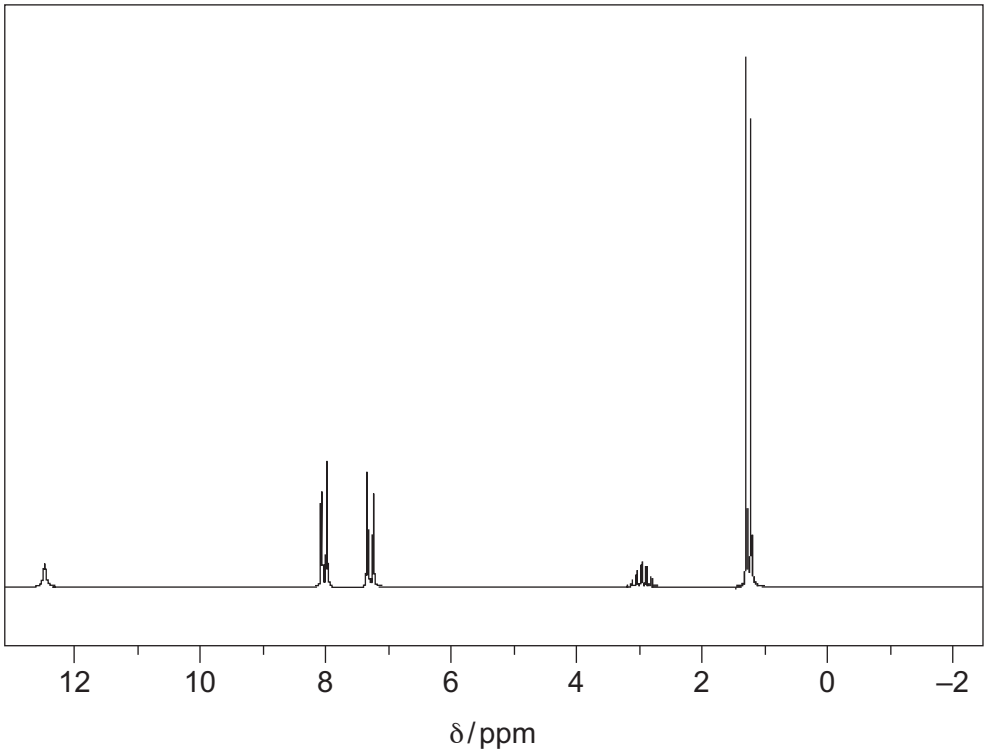


Compound A

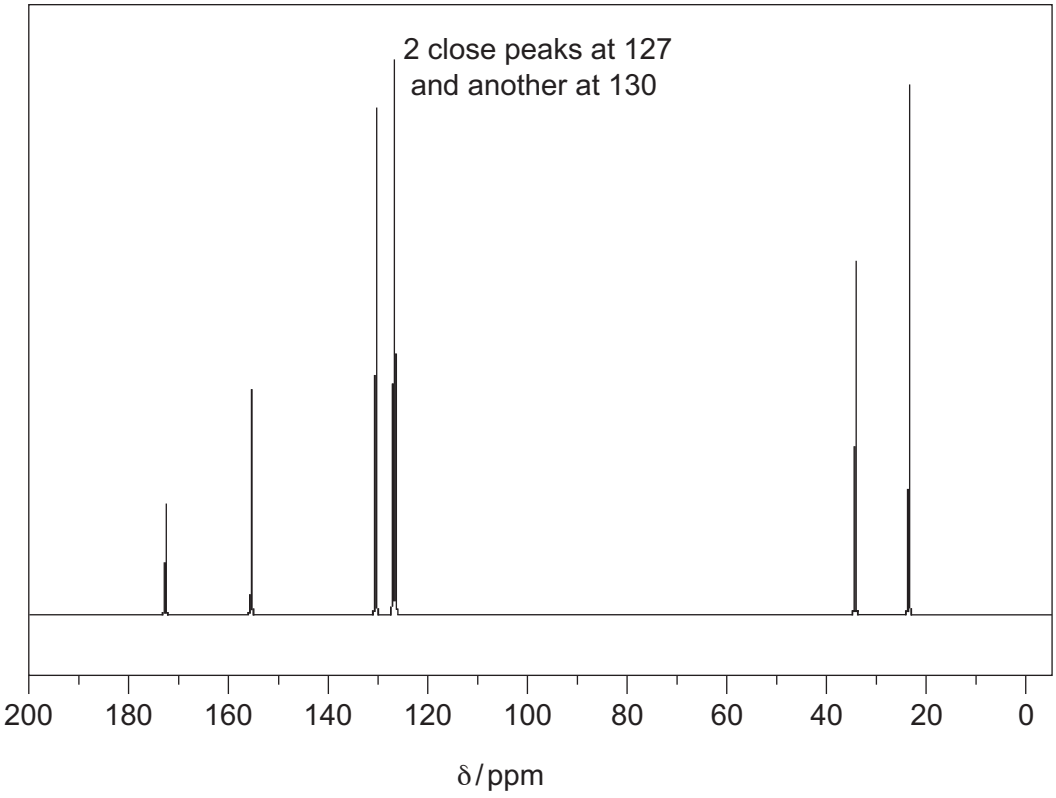
[2]

(e)* An aromatic acid has the formula $C_{10}H_{12}O_2$. Its NMR spectra are shown below.

^{1}H NMR



^{13}C NMR



You may do working on this page but only your answer on page 9 will be marked.

Identify the aromatic acid.

Show how evidence from **both** spectra relates to the structure.

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..... **[6]**

Additional answer space if required:

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3 There is concern about the amount of carbon dioxide produced when methane is burned in domestic gas boilers.

Hydrogen is being investigated as an alternative gas that could be delivered through adaptations of the present gas pipes to adapted boilers.

(a) The traditional source of industrial hydrogen uses two processes that have the overall equation shown in **Equation 3.1**.

$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$ $\Delta H = +165\,kJ\,mol^{-1}$ **Equation 3.1**

A high temperature is needed to obtain a reasonable yield of hydrogen in a reasonable time.

(i) A student says that a **low pressure** is best for the industrial manufacture of hydrogen in **Equation 3.1**.

Discuss the student's statement.

Use relevant chemistry to support your answer.

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..... **[4]**

Equation 3.1 is repeated.

$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$ $\Delta H = +165\,kJ\,mol^{-1}$ **Equation 3.1**

$$K_c = \frac{[CO_2]\,[H_2]^4}{[CH_4]\,[H_2O]^2}$$

(ii) A mixture of $1.00\,mol\,dm^{-3}$ $CH_4(g)$ and $1.00\,mol\,dm^{-3}$ $H_2O(g)$ is allowed to reach equilibrium at 673 K in a container of volume $1.00\,dm^3$.

The equilibrium concentration of H_2 is found to be $0.0705\,mol\,dm^{-3}$.

Calculate a value for the equilibrium constant, K_c, for **Equation 3.1** at 673 K and give its units.

K_c = ... units ..... **[4]**

(iii) K_c for the reaction is then measured again at an increased pressure.

Would the value of K_c be larger, smaller or the same?

Give a reason for your answer.

.....

..... **[1]**

Equation 3.1 is repeated.

$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$ $\Delta H = +165\,kJ\,mol^{-1}$ **Equation 3.1**

(iv) The table shows some entropy data.

Substance	$S^\ominus$ / J mol^{-1} K^{-1}
$CH_4(g)$	186
$CO_2(g)$	214
$H_2(g)$	130
$H_2O(g)$	189

Use the data to show that $\Delta S^\ominus_{sys} = +170\,J\,mol^{-1}\,K^{-1}$ for the reaction in **Equation 3.1**.

[1]

(v) Use calculations to determine if the forward reaction in **Equation 3.1** is feasible at 750 °C.

Give a reason for your answer.

.....

..... **[3]**

(vi) The carbon dioxide produced by the process in **Equation 3.1** is a greenhouse gas.

Describe **two** ways in which greenhouse gases in the troposphere cause warming when they are irradiated by infrared radiation from the Earth.

1 .....

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2 .....

.....

.....

[3]

(b) A potentially 'greener' method of making hydrogen is by electrolysis of acidified water.

(i) The equation for the reaction at the cathode is shown.

$2H^+ + 2e^- \rightarrow H_2$

Complete and balance the equation for the reaction at the anode:

.....$H_2O \rightarrow 4e^-$ + ... + ...

[2]

(ii) A mole of electrons is 96 500 coulombs. A coulomb is 1 amp flowing for 1 second.

How long (in hours) would it take for a current of 100.0 amps to produce 20.0 g of hydrogen by electrolysis?

Assume 100% efficiency.

time = ... hours **[3]**

(iii) A student says that producing hydrogen by electrolysis is **not** 'green' because fossil fuels are used to make the electricity.

Discuss this statement.

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..... **[2]**

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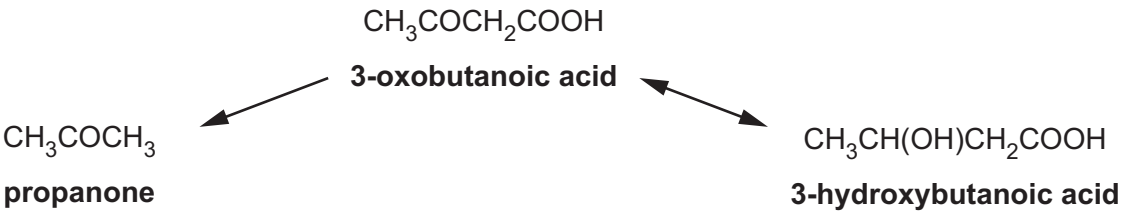
4 3-oxobutanoic acid is formed from carboxylic acids in the liver in the human body. It is then broken down to produce propanone and 3-hydroxybutanoic acid.



These three compounds are known as 'ketone bodies' and are always present in human blood.

(a) Name the **type** of reaction by which 3-oxybutanoic acid is converted to 3-hydroxybutanoic acid.

..... **[1]**

(b) A concentration of greater than 6×10^{-4} mol dm^{-3} of ketone bodies in the bloodstream is known as 'ketosis'.

Calculate the **mass** of propanone (M_r 58) (in grams) in 100 cm^3 of blood that contains 6×10^{-4} mol dm^{-3} of propanone.

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

mass = ... g **[2]**

(c) Ketosis can be detected by the presence of propanone in the breath.

Propanone can be recognised from its mass spectrum.

(i) State a method of separating propanone vapour from human breath, allowing it to be analysed by a mass spectrometer.

..... **[1]**

(ii) Peaks are found at m/z values 15, 43 and 59 in the mass spectrum of propanone (M_r 58).

Give the origin of these peaks.

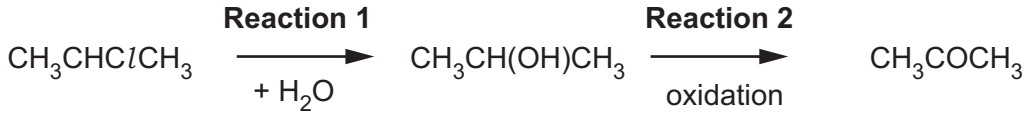
15 .....

43 .....

59 .....

[3]

(d) A student proposes a reaction sequence for the formation of propanone.



$CH_3CHCl CH_3$ → $CH_3CH(OH)CH_3$ → CH_3COCH_3

2-chloropropane **propan-2-ol** **propanone**

(i) Name the **mechanism** of **Reaction 1**.

..... **[1]**

(ii)* In **Reaction 1** the haloalkane is hydrolysed.

The general equation is:

$RX + H_2O \rightarrow ROH + H^+ + X^-$ (where X is a halogen atom)

The rate of this reaction for different halogens could depend on either the bond enthalpy or the bond polarisation of the C–X bond.

It is not possible to predict which by chemical theory.

Explain how the bond enthalpy **and** how the bond polarisation could affect the rate.

Design suitable laboratory experiments to show if bond enthalpy or bond polarisation has the greater effect on the rate.

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..... **[6]**

Additional answer space if required:

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(e) Classify propan-2-ol, $CH_3CH(OH)CH_3$, as primary, secondary or tertiary and give a reason for your answer.

Classification (primary, secondary or tertiary) .....

Reason: .....

.....

[2]

(f) Propan-1-ol is oxidised to an aldehyde rather than a ketone.

Describe a laboratory test, and its result, that would distinguish this aldehyde from propanone.

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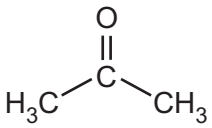
..... **[2]**

(g) Propanone reacts with CN^- ions in the presence of acid.

(i) Complete the mechanism for this reaction.

Show curly arrows, charges, lone pairs and the product.



[3]

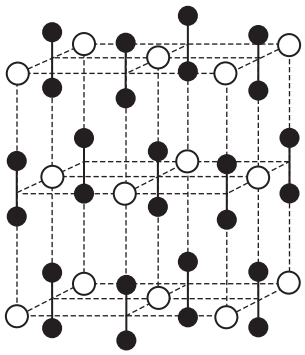
(ii) Name the functional group formed in the product from **(i)**.

..... **[1]**

5 This question concerns the Advance Notice Article 'Calcium carbide' that is included as an insert with this paper.

(a) A diagram of the structure of calcium carbide is shown below.

Label a cation and an anion to show how the ions are arranged in the structure.



[2]

(b) The industrial manufacture of calcium carbide has benefits and disadvantages for modern society.

From the article, suggest **two** benefits and **two** disadvantages.

Benefit 1 .....

.....

Benefit 2 .....

.....

Disadvantage 1 .....

.....

Disadvantage 2 .....

.....

[4]

(c) 1.1 kg of a sample of impure calcium carbide produces 0.33 m^3 of acetylene (at RTP) when reacted with water.

Calculate the percentage purity of the sample.

percentage purity = ... % **[3]**

(d) **(i)** Acetylene (ethyne) burns in a carbide lamp to form carbon dioxide and water. Some unreacted carbon is also formed that glows and gives light.

Write a possible chemical equation for the combustion of acetylene to give carbon dioxide and carbon.

[1]

(ii) Impure calcium carbide contains calcium phosphide.

The phosphide ion is P^{3-}.

Calcium phosphide reacts with water to form PH_3.

Suggest a chemical equation for this reaction.

[2]

(e) (i) Complete a 'dot-and-cross' diagram for cyanamide.

H

H N C N

[2]

(ii) Suggest, with reasons, the bond angle for N–C–N in cyanamide.

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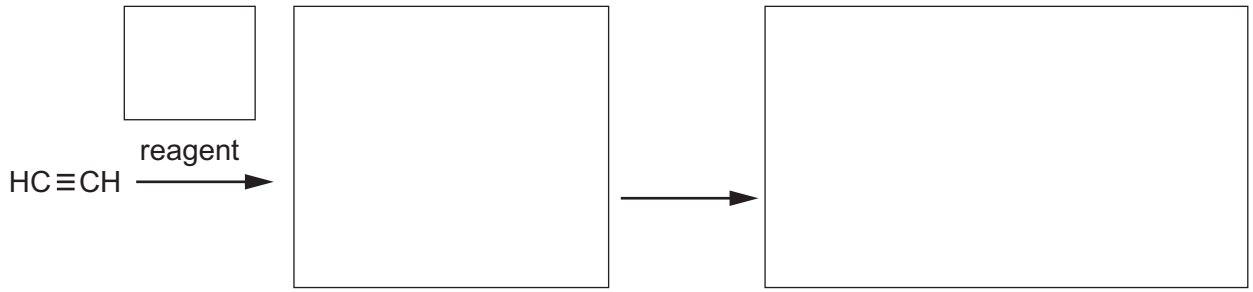
..... **[3]**

(f) PVC has the systematic name poly(chloroethene).

Complete the sequence below for the formation of PVC from acetylene.

Write a structural formula in each box.



[3]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).