



## Cambridge International AS & A Level

CANDIDATE  
NAME

CENTRE  
NUMBER

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**CHEMISTRY**

**9701/21**

Paper 2 AS Level Structured Questions

**October/November 2021**

**1 hour 15 minutes**

You must answer on the question paper.

You will need: Data booklet

### INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

### INFORMATION

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **16** pages. Any blank pages are indicated.



## 2

Answer **all** the questions in the spaces provided.

1 Sulfides are compounds that contain sulfur but not oxygen.

(a) Carbon disulfide,  $\text{CS}_2$ , is a volatile liquid at room temperature and pressure.

(i) State the meaning of *volatile*.

..... [1]

(ii) Draw a 'dot-and-cross' diagram of the  $\text{CS}_2$  molecule.

[2]

(iii) Suggest the bond angle in a molecule of  $\text{CS}_2$ .

..... [1]

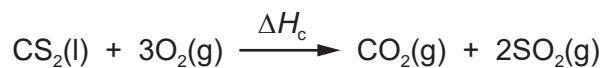
(iv)  $\text{CS}_2$  is a liquid under room conditions, while  $\text{CO}_2$  is a gas.

Explain what causes the difference in the physical properties between  $\text{CS}_2$  and  $\text{CO}_2$ .

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

## 3

(b) The enthalpy change of combustion of  $\text{CS}_2(\text{l})$  is represented by the following equation.



(i) Define *enthalpy change of combustion*.

.....

.....

..... [2]

(ii) The table shows the enthalpy changes of formation of  $\text{CS}_2(\text{l})$ ,  $\text{CO}_2(\text{g})$  and  $\text{SO}_2(\text{g})$ .

compound	enthalpy change of formation, $\Delta H_f/\text{kJ mol}^{-1}$
$\text{CS}_2(\text{l})$	+89.7
$\text{CO}_2(\text{g})$	-394
$\text{SO}_2(\text{g})$	-297

Use the data in the table to calculate the enthalpy change of combustion,  $\Delta H_c$ , of  $\text{CS}_2(\text{l})$ , in  $\text{kJ mol}^{-1}$ .

Show your working.

$$\Delta H_c \text{ of } \text{CS}_2(\text{l}) = \dots\dots\dots \text{kJ mol}^{-1}$$

[2]

(c) Hydrogen sulfide gas,  $\text{H}_2\text{S}(\text{g})$ , is slightly soluble in water. It acts as a weak acid in aqueous solution.

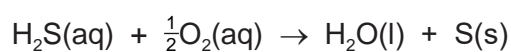
(i) State the meaning of *weak acid*.

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

(ii) Give the formula of the conjugate base of  $\text{H}_2\text{S}$ .

..... [1]

(iii)  $\text{H}_2\text{S}(\text{aq})$  reacts slowly with oxygen dissolved in water. The reaction is represented by the following equation.

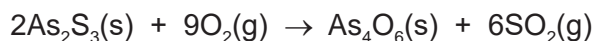


Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

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

- (d) The compound  $\text{As}_2\text{S}_3$  is a common mineral.

When  $\text{As}_2\text{S}_3$  is heated strongly in air, it forms a mixture of products, as shown.



- (i) A sample containing 0.198 g  $\text{As}_2\text{S}_3$  is placed in 0.100 dm<sup>3</sup> of pure oxygen, an excess, in a reaction chamber connected to a gas syringe at room temperature.

The reactants are heated until no further change is observed. The products are then allowed to cool to room temperature.

Calculate the volume, in dm<sup>3</sup>, of gas present at the end of the experiment.

The molar volume of gas is 24.0 dm<sup>3</sup> mol<sup>-1</sup> under these conditions. Assume that the pressure is constant throughout the experiment.

Show your working.

volume of gas remaining = ..... dm<sup>3</sup>  
[4]

- (ii) State the environmental consequences of releasing  $\text{SO}_2(\text{g})$  into the atmosphere.

..... [1]

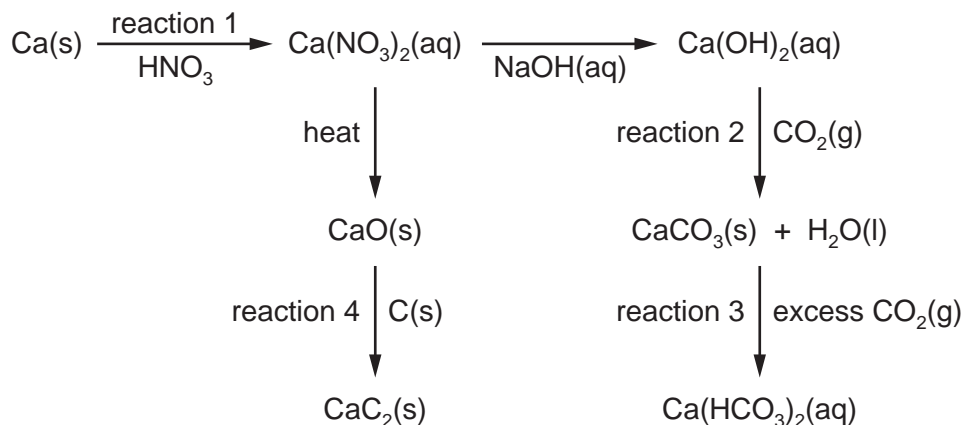
- (iii)  $\text{SO}_2(\text{g})$  can be removed from the air by reacting it with  $\text{NaOH}(\text{aq})$ .

Construct an equation for the reaction of  $\text{SO}_2(\text{g})$  with  $\text{NaOH}(\text{aq})$ . Include state symbols.

..... [2]

[Total: 21]

2 The reaction scheme shows some reactions of calcium.



(a) (i) Reaction 1 produces  $\text{Ca(NO}_3)_2$  and one other product.

Identify the other product.

..... [1]

(ii) Construct an equation for the thermal decomposition of  $\text{Ca(NO}_3)_2(\text{s})$ .

..... [1]

(iii) State the trend in the thermal stability of the Group 2 nitrates down the group.

..... [1]

(iv) In reaction 3, excess  $\text{CO}_2$  is bubbled through water containing  $\text{CaCO}_3$ . A solution of  $\text{Ca(HCO}_3)_2(\text{aq})$  forms.

Construct an equation for reaction 3.

..... [1]

(b) Describe how  $\text{Ca(OH)}_2$  is used in agriculture.

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

7

(c) In reaction 4, calcium carbide,  $\text{CaC}_2$ , is formed from  $\text{CaO}$ .

$\text{CaC}_2$  contains the  $\text{C}_2^{2-}$  anion. Each carbon in  $\text{C}_2^{2-}$  is sp hybridised.

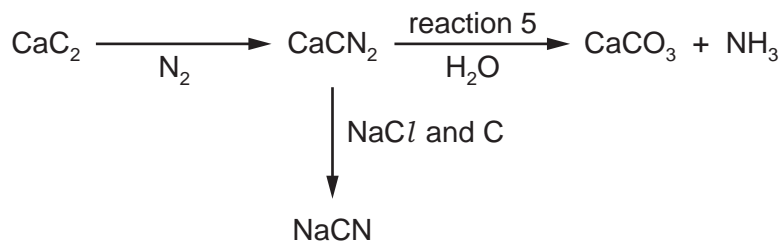
(i) Describe how sp hybridised orbitals are formed.

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

(ii) Sketch a diagram to show how two sp hybrid orbitals can form a sigma ( $\sigma$ ) bond.

[2]

(d) The flowchart shows some reactions of  $\text{CaC}_2$ .



(i) Reaction 5 can be used to prepare  $\text{NH}_3$ .



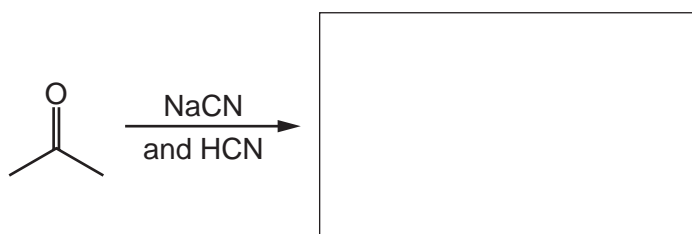
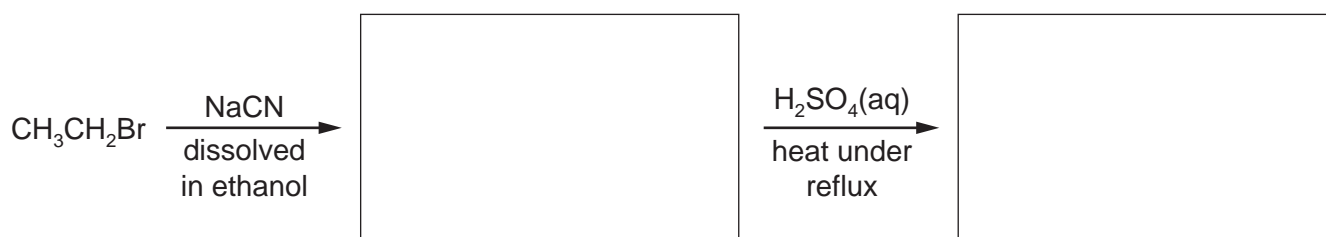
Calculate the minimum mass, in tonnes, of calcium cyanamide,  $\text{CaCN}_2$ , that is required to produce  $1.50 \times 10^6$  tonnes of  $\text{NH}_3$ .

Show your working.

$$1 \text{ tonne} = 1.00 \times 10^6 \text{ g}$$

minimum mass of  $\text{CaCN}_2 = \dots\dots\dots$  tonnes  
[2]

(ii) Draw the structure of the organic products formed in the following reactions.



[3]

[Total: 13]



3 Phosphorus is a reactive Period 3 element.

(a) Phosphorus has several allotropes. Details of two allotropes are given.

allotrope of phosphorus	formula	melting point/°C
white	P <sub>4</sub>	44
red	P	590

(i) White phosphorus and red phosphorus both have covalent bonding.

Suggest the types of structure shown by white phosphorus (P<sub>4</sub>) and red phosphorus (P).

Explain why red phosphorus (P) has a higher melting point than white phosphorus (P<sub>4</sub>).

structure of P<sub>4</sub> .....

structure of P .....

explanation .....

.....

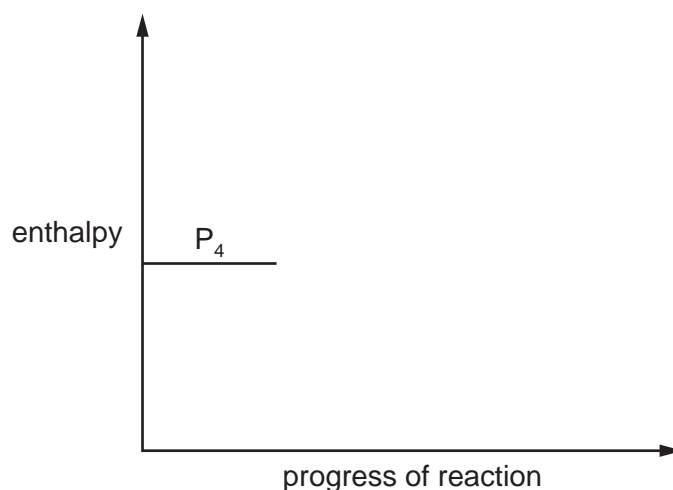
.....

[3]

(ii) Red phosphorus (P) forms when white phosphorus (P<sub>4</sub>) is exposed to sunlight.

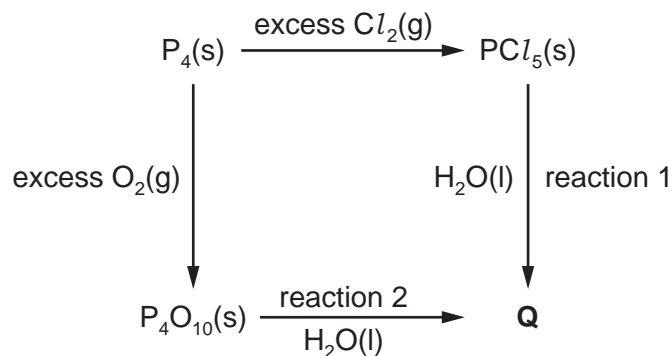


Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P<sub>4</sub>).



[1]

(b) Some reactions of  $P_4(s)$  are shown in the reaction scheme.



(i) State the oxidation number of phosphorus in  $P_4O_{10}$ .

..... [1]

(ii) Deduce the identity of **Q** and hence construct chemical equations for reactions 1 and 2.

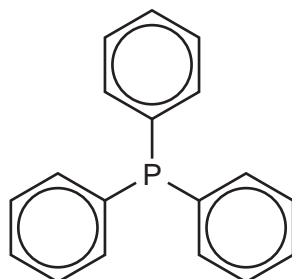
reaction 1  $PCl_5 + \dots H_2O \rightarrow \dots$

reaction 2  $P_4O_{10} + \dots H_2O \rightarrow \dots$

[2]

(c) Triphenylphosphine is used in a type of reaction known as a *Wittig reaction*.

triphenylphosphine

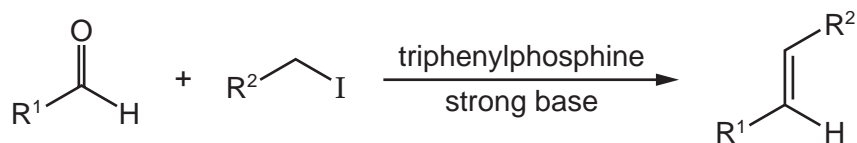


where =  $-C_6H_5$

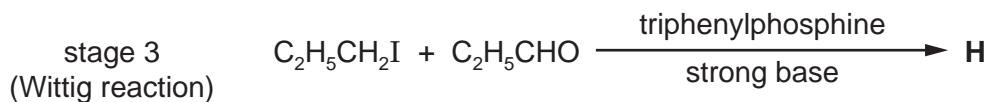
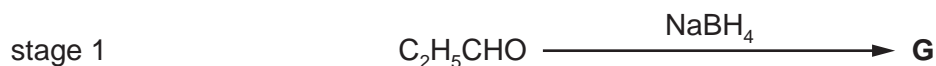
(i) Give the empirical formula of triphenylphosphine.

..... [1]

In a Wittig reaction, an aldehyde reacts with a halogenoalkane to form an alkene. The conversion is shown in the following unbalanced equation.



Compound **H** can be made from propanal,  $\text{C}_2\text{H}_5\text{CHO}$ . Stage 3 in the reaction scheme is a Wittig reaction.



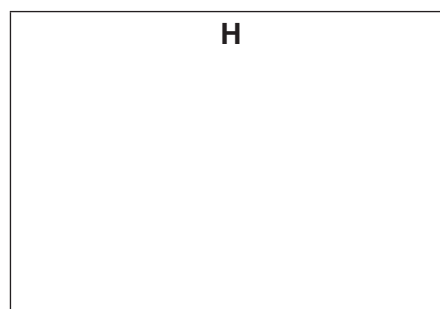
(ii) State the types of reaction that occur in stages 1 and 2.

stage 1 .....

stage 2 .....

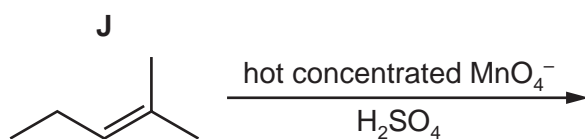
[2]

(iii) Draw the structures of **G** and **H** in the boxes provided.



[2]

(d) Identify the organic products formed when compound **J**, shown below, is heated with hot concentrated acidified manganate(VII) ions.

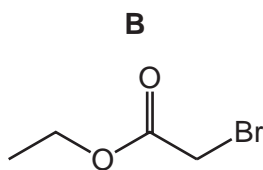


[2]

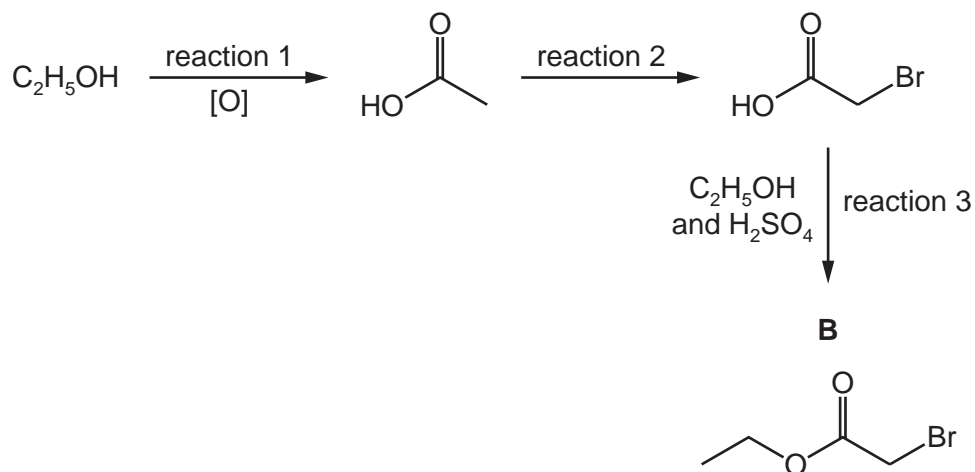
[Total: 14]

12

4 Compound **B** is a liquid with a fruity smell.



The reaction scheme shows how **B** can be made from ethanol,  $C_2H_5OH$ .



(a) (i) Reaction 1 is an oxidation reaction.

Give the reagent(s) and conditions required for reaction 1.

reagent(s) .....

conditions .....

[2]

(ii) Construct an equation to represent reaction 1.

Use [O] to represent an oxygen atom from the oxidising agent in this reaction.

..... [1]

(iii) Suggest the type of reaction that occurs in reaction 2.

..... [1]

(iv)  $H_2SO_4$  acts as a homogeneous catalyst in reaction 3.

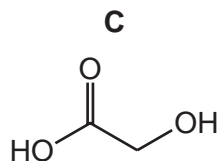
Explain why  $H_2SO_4$  is described as *homogeneous*.

.....

..... [1]

13

(b) Reaction 2 needs to take place in the absence of water to prevent formation of compound **C**.



If **C** is present in the reaction mixture of reaction 3, a different compound, compound **D**, will also form. Compound **D** has two identical functional groups.

The infrared spectrum of **D** shows strong absorptions at  $1100\text{ cm}^{-1}$  and  $1720\text{ cm}^{-1}$ , but no absorption due to O–H bonds.

Use the *Data Booklet* to identify the functional group present in **D**.

Explain your answer as fully as you can.

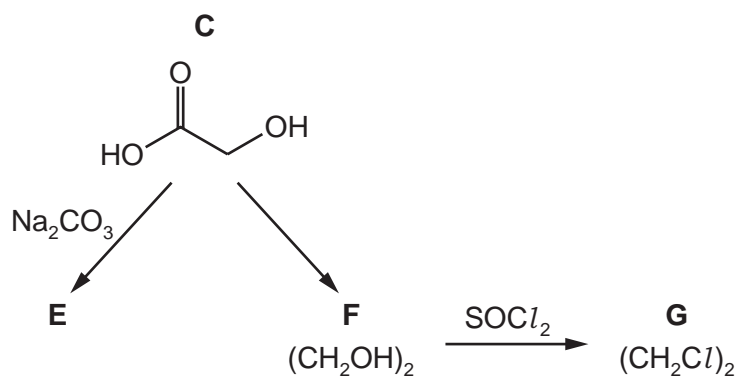
.....

.....

.....

..... [3]

(c) Some other reactions of **C** are shown.



(i) Draw the structure of **E**.

[1]

(ii) Suggest why  $\text{NaBH}_4$  is not a suitable reagent to make **F**,  $(\text{CH}_2\text{OH})_2$ , from **C**. Explain your answer.

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

(iii) Construct an equation for the reaction of  $(\text{CH}_2\text{OH})_2$  with  $\text{SOCl}_2$  to form **G**,  $(\text{CH}_2\text{Cl})_2$ .

..... [1]

(d) Explain why **C** is very soluble in water.

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

[Total: 12]



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