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CHEMISTRY

9701/21

Paper 2 AS Level Structured Questions

May/June 2017

1 hour 15 minutes

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

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Answer **all** questions.

Electronic calculators may be used.

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This document consists of **10** printed pages and **2** blank pages.



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

- 1 Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds.

(a) Define the term *relative molecular mass*.

.....

.....

.....

..... [2]

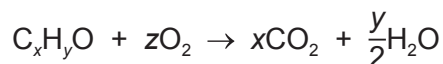
- (b) **T** is an alcohol, C_xH_yO . A gaseous sample of **T** occupied a volume of 20 cm^3 at 120°C and 100 kPa .

The sample was completely burned in 200 cm^3 of oxygen (an excess). The final volume, measured under the same conditions as the gaseous sample, was 250 cm^3 .

Under these conditions, all water present is vaporised. Removal of the water vapour from the gaseous mixture decreased the volume to 170 cm^3 .

Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to 110 cm^3 .

The equation for the complete combustion of **T** can be represented as shown.



- (i) Use the data given to calculate the value of x .

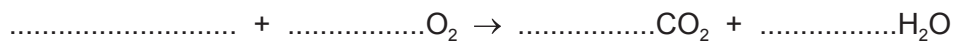
$x = \dots\dots\dots$ [1]

- (ii) Use the data given to calculate the value of y .

$y = \dots\dots\dots$ [1]

If you were unable to calculate values for x and y then use $x = 4$ and $y = 10$ for the remaining parts of this question. These are **not** the correct values.

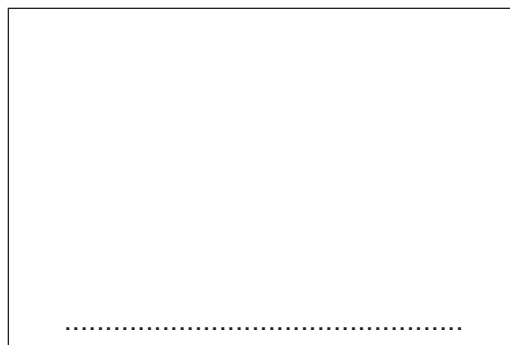
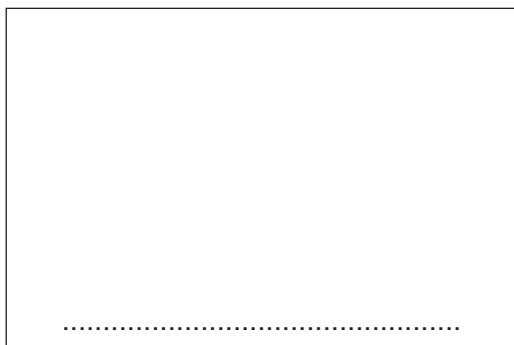
(iii) Complete the equation for the complete combustion of the alcohol, **T**.



[1]

(iv) Give the skeletal formulae for two possible structures of **T**.

Name each alcohol.



[2]

(v) Use the general gas equation to calculate the mass of **T** present in the original 20 cm^3 gaseous sample, which was measured at 120°C and 100 kPa .

Give your answer to **three** significant figures. Show your working.

mass = ... g [3]

[Total: 10]

2 Structure and bonding can be used to explain many of the properties of substances.

(a) Copper, ice, silicon(IV) oxide, iodine and sodium chloride are all crystalline solids.

Complete the table with:

- the name of a type of bonding found in each crystalline solid,
- the type of lattice structure for each crystalline solid.

crystalline solid	type of bonding	type of lattice structure
copper		
ice		
silicon(IV) oxide		
iodine		
sodium chloride		

[5]

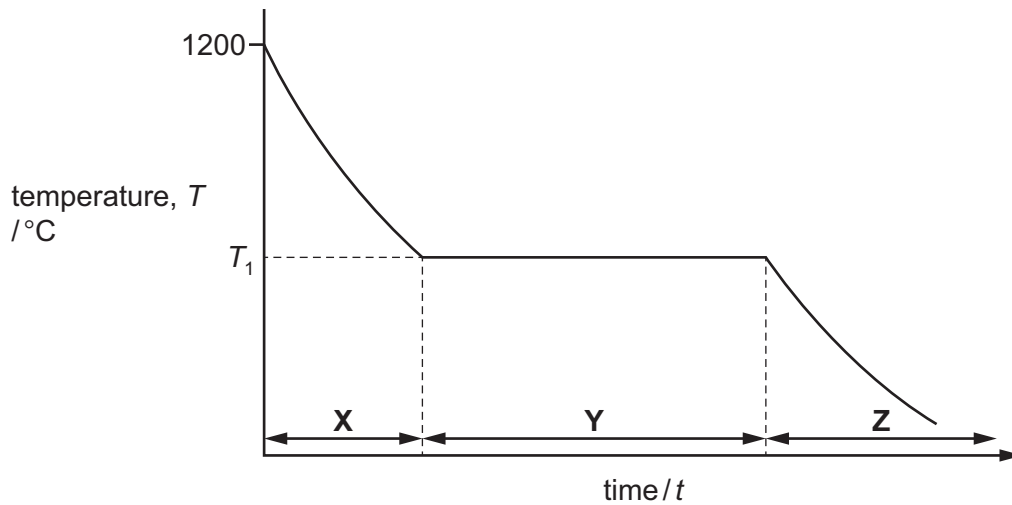
(b) (i) Name the strongest type of intermolecular force in ice.

..... [1]

(ii) Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

- (c) The graph represents how the temperature of a sample of copper (melting point 1085°C) changes as it is gradually cooled from 1200°C .



- (i) Identify the state(s) of matter present during each stage of the process shown in the graph.

X

Y

Z

[2]

- (ii) State what is happening to the energy and movement of the particles in the copper during stage **X**.

.....

 [2]

- (iii) Explain why the temperature stays constant at T_1 during stage **Y**.

.....

 [2]

[Total: 15]

- (a) The positions of some elements are indicated. The letters used are **not** the symbols of the elements.

E																B	H			
	D																			
											A									
F	G													C						

From the elements labelled, give the letter for;

- (i) the element that forms an amphoteric oxide, ... [1]
- (ii) the element with the highest first ionisation energy, ... [1]
- (iii) the element that forms a soluble hydroxide and an insoluble sulfate, ... [1]
- (iv) the most volatile element in a group that contains elements in all three states of matter at room temperature and pressure, ... [1]
- (v) the element that forms the largest cation. [1]

- (b)** The elements in Group 2 all react with oxygen and with water.

- (i) State and explain the conditions needed for magnesium to react with oxygen.

..... [2]

- (ii) State what would be seen during the reaction in (b)(i).

..... [1]

- (iii) Write an equation for the reaction of magnesium with cold water. Include state symbols.

..... [2]

(c) The carbonates and nitrates of the elements in Group 2 can all be decomposed by heating.

(i) Write an equation for the thermal decomposition of magnesium nitrate.

..... [1]

(ii) The thermal decomposition of calcium carbonate forms a solid product that is industrially important. This solid product reacts with water to form a compound commonly known as slaked lime.

Write equations for the thermal decomposition of calcium carbonate and the reaction of the solid product to form slaked lime.

thermal decomposition

formation of slaked lime

[2]

(d) Calcium carbonate and calcium hydroxide both have an important use in agriculture.

(i) Describe this use and explain what makes these two compounds suitable for it.

.....

.....

..... [2]

(ii) Write an ionic equation to illustrate this use of calcium carbonate.

..... [1]

[Total: 16]

4 **P**, **Q** and **R** all have the molecular formula $\text{C}_3\text{H}_6\text{O}$. They are all structural isomers of each other.

P and **Q** each contain an oxygen atom bonded directly to a carbon atom that is sp^2 hybridised.
R contains an oxygen atom bonded directly to a carbon atom that is sp^3 hybridised.

(a) (i) Explain the meaning of the term *structural isomers*.

.....

 [2]

(ii) Explain how sp^2 and sp^3 hybridisation can occur in carbon atoms.

sp^2 hybridisation

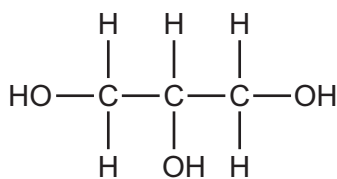
 sp^3 hybridisation
 [2]

(iii) State the bond angles normally associated with each type of hybridisation in carbon atoms.

sp^2
 sp^3 [2]

(b) **R** contains two different functional groups, one of which is an alkene group.

R reacts with cold, dilute, acidified manganate(VII) ions to form propane-1,2,3-triol.



propane-1,2,3-triol

(i) Give the displayed formula of **R**.

[1]

- (ii) State the type of reaction and what you would observe when **R** reacts with bromine water.

.....
 [2]

- (iii) Draw the structure of the product formed when **R** reacts with bromine water.

[1]

- (iv) Identify the gaseous product formed when **R** reacts with hot, concentrated, acidified manganate(VII) ions.

..... [1]

- (c) **P** and **Q** ($\text{C}_3\text{H}_6\text{O}$) both form an orange precipitate when reacted with 2,4-DNPH. Only **Q** produces a yellow precipitate when reacted with alkaline aqueous iodine.

- (i) Name **P** and **Q**.

P

Q

[2]

- (ii) Identify the yellow precipitate formed by the reaction of **Q** with alkaline aqueous iodine.

..... [1]

- (d) **P** and **Q** each react with hydrogen cyanide to form a single product.

The product formed from **P** exists as a pair of optical isomers.

The product formed from **Q** does not exhibit optical isomerism.

- (i) Explain the meaning of the term *optical isomers*.

.....

 [2]

- (ii) Ethanal, CH_3CHO , also reacts with hydrogen cyanide. The product of this reaction is $\text{CH}_3\text{CH}(\text{OH})\text{CN}$.

Draw the mechanism of this reaction.

Include all necessary charges, dipoles, lone pairs and curly arrows.

[3]

[Total: 19]

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9701/22

May/June 2017

1 hour 15 minutes

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

- 1 The composition of atoms and ions can be determined from knowledge of atomic number, nucleon number and charge.

(a) Complete the table.

atomic number	nucleon number	number of electrons	number of protons	number of neutrons	symbol
3		2			${}^6_3\text{Li}^+$
		23	26	32	

[2]

- (b) Boron occurs naturally as a mixture of two stable isotopes, ${}^{10}\text{B}$ and ${}^{11}\text{B}$. The relative isotopic masses and percentage abundances are shown.

isotope	relative isotopic mass	abundance / %
${}^{10}\text{B}$	10.0129	19.78
${}^{11}\text{B}$	to be calculated	80.22

- (i) Define the term *relative isotopic mass*.

.....
 [2]

- (ii) Calculate the relative isotopic mass of ${}^{11}\text{B}$.

Give your answer to **six** significant figures. Show your working.

[2]

[Total: 6]

2 Nitrogen gas, N_2 , is very unreactive.

(a) Explain why nitrogen gas is so unreactive.

.....

 [2]

(b) Despite the low reactivity of N_2 , oxides of nitrogen occur in the atmosphere through both natural and man-made processes.

(i) Explain why oxides of nitrogen can be produced by internal combustion engines.

.....

 [2]

(ii) State and explain, using a suitable equation, how oxides of nitrogen produced by internal combustion engines can be prevented from reaching the atmosphere.

.....
 [2]

(iii) State the role of nitrogen dioxide, NO_2 , in the formation of acid rain by oxides of sulfur. Write suitable equations to explain this role.

role
 equation 1
 equation 2 [3]

(iv) Suggest an equation to show how NO_2 can contribute **directly** to acid rain.

..... [1]

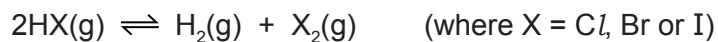
(c) Explain how the uncontrolled use of nitrate fertilisers on land can lead to a severe reduction in water quality in rivers.

.....

 [3]

[Total: 13]

- 3 The hydrogen halides, HCl , HBr and HI , can undergo thermal decomposition. In a sealed container an equilibrium is established according to the equation shown.



- (a) Some bond energies are shown in the table.

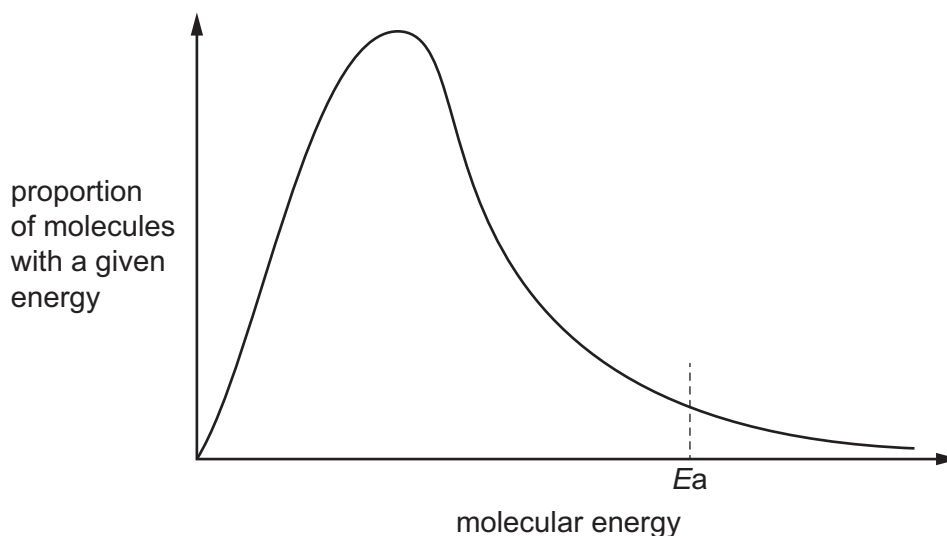
	bond energy / kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

Use these data to calculate a value for the enthalpy change, ΔH , for the thermal decomposition of hydrogen bromide, HBr , according to the equation shown.

$$\Delta H = \dots\dots\dots \text{kJ mol}^{-1} \quad [1]$$

- (b) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) With reference to the curves, state and explain the effect of increasing temperature on the **rate** of decomposition of HBr.

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

- (iii) The decomposition of HBr is endothermic.

State the effect of increasing temperature on the **percentage** of HBr that decomposes.
Use Le Chatelier's principle to explain your answer.

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

- (iv) At 700 K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.

Explain this difference with reference to bond strengths and the factors that affect them.

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

- (c) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2 .

- (i) Calculate the amounts, in mol, of H_2 and HCl present in the equilibrium mixture.

$\text{H}_2 = \dots\dots\dots$ mol

$\text{HCl} = \dots\dots\dots$ mol
[2]

- (ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of $\text{HCl} = \dots\dots\dots$

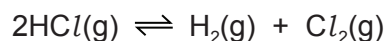
mole fraction of $\text{H}_2 = \dots\dots\dots$

mole fraction of $\text{Cl}_2 = \dots\dots\dots$
[1]

- (d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HCl	0.88
H_2	0.06
Cl_2	0.06

- (i) Write the expression for the equilibrium constant, K_p , for the decomposition of HCl .



$K_p =$

[1]

- (ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

.....

..... [1]

- (iii) Calculate the value of K_p for this experiment.

$K_p =$ [1]

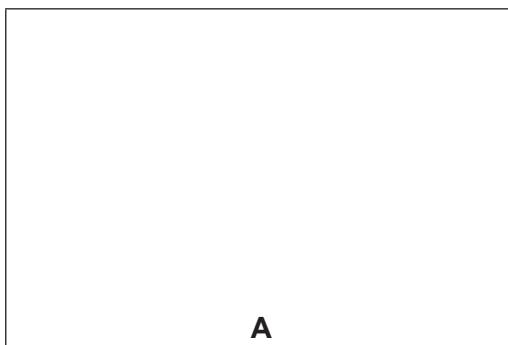
[Total: 18]

- 4 (a) The hydrocarbons **A**, C_4H_{10} , and **B**, C_4H_8 , are both unbranched.

A does **not** decolourise bromine.

B decolourises bromine and shows geometrical isomerism.

- (i) Draw the skeletal formula of **A**.



[1]

- (ii) The hydrocarbon **A**, C_4H_{10} , has a branched isomer.

Suggest why unbranched **A** has a higher boiling point than its branched isomer.

.....

.....

.....

.....

..... [2]

- (iii) Give the structural formula of **B**.

..... [1]

- (iv) Explain why **B** shows geometrical isomerism.

.....

.....

.....

..... [2]

- (v) Draw the mechanism of the reaction of **B** with bromine, Br_2 .
Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

- (vi) Explain the origin of the dipole on Br_2 in this mechanism.

.....

 [1]

- (b) The alcohols **C** and **D** are isomers of each other with molecular formula $\text{C}_4\text{H}_{10}\text{O}$. Both isomers are branched.

When **C** is heated under reflux with acidified potassium dichromate(VI) no colour change is observed.

When **D** is heated under reflux with acidified potassium dichromate(VI) the colour of the mixture changes from orange to green and **E**, $\text{C}_4\text{H}_8\text{O}_2$, is produced.

E reacts with aqueous sodium carbonate to form carbon dioxide gas.

- (i) Identify **C**, **D** and **E**.

C	D	E
----------	----------	----------

[3]

- (ii) Write the equation for the reaction between **E** and aqueous sodium carbonate.

..... [1]

(c) The isomers **F** and **G**, $C_5H_{10}O$, both form an orange precipitate when reacted with 2,4-DNPH.

F is unbranched and reacts with alkaline aqueous iodine to produce a yellow precipitate.

G does not react with alkaline aqueous iodine. It contains a chiral centre and produces a silver mirror when warmed with Tollens' reagent.

(i) Name the yellow precipitate produced by the reaction between **F** and alkaline aqueous iodine.

..... [1]

(ii) Give the structural formula of **F** and of **G**.

F

G

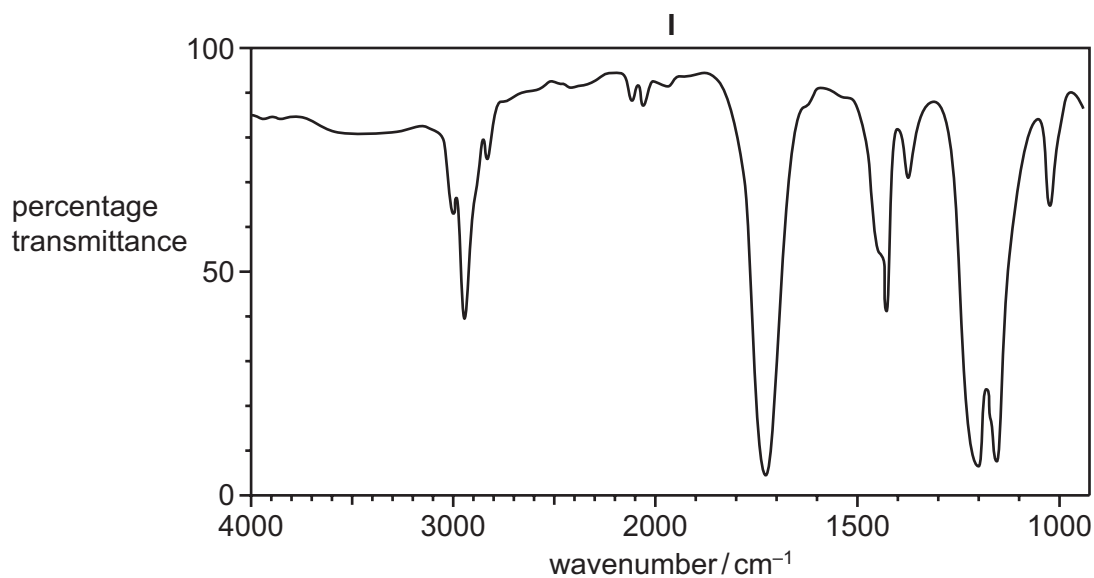
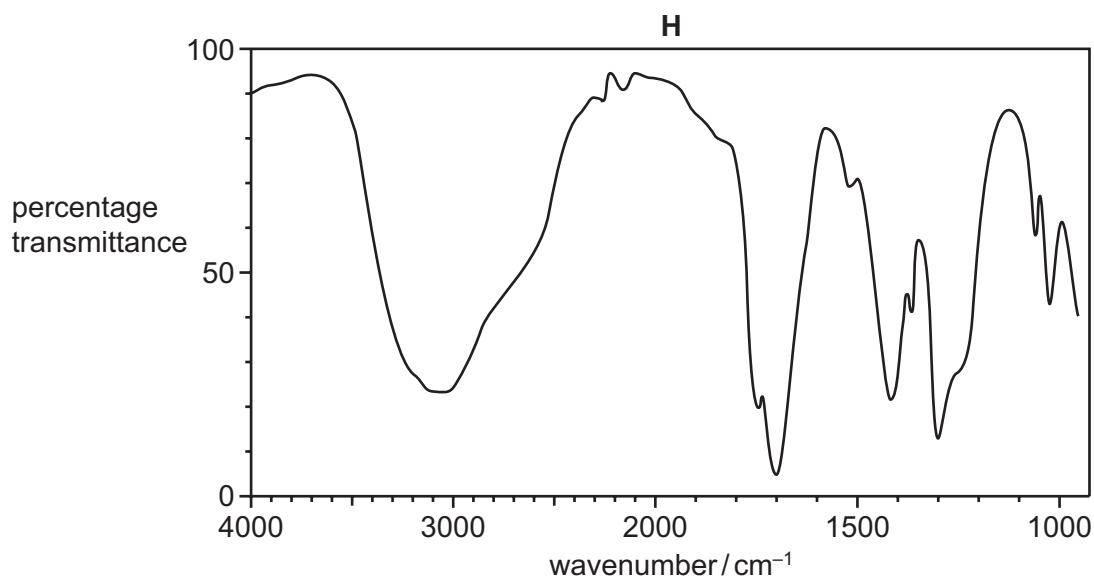
[2]

(iii) Explain the meaning of the term *chiral centre*.

.....

..... [1]

- (d) **H** and **I** are isomers with molecular formula $C_2H_4O_2$. The infra-red spectra of isomers **H** and **I** are shown.



- (i) Identify the bonds responsible for the principal peaks above 1500 cm^{-1} in each spectrum.

spectrum of **H**

.....

spectrum of **I**

.....

[2]

- (ii) Name **H** and **I**.

H

I

[2]

[Total: 23]

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

- 1 Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds. Combustion data cannot distinguish between different structural isomers.

(a) Define the term *structural isomers*.

.....

.....

.....

..... [2]

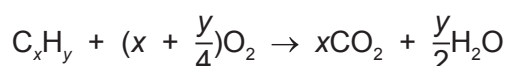
- (b) **P** is a hydrocarbon, C_xH_y . A gaseous sample of **P** occupied a volume of 25 cm^3 at 37°C and 100 kPa .

The sample was completely burned in 200 cm^3 of oxygen (an excess).

The final volume, measured under the same conditions as the gaseous sample (so that the water produced is liquid and its volume can be ignored), was 150 cm^3 .

Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to 50 cm^3 .

The equation for the complete combustion of **P** can be represented as shown.



- (i) Use the data given to calculate the value of x .

$$x = \dots\dots\dots [1]$$

- (ii) Use the data given to calculate the value of $(x + \frac{y}{4})$.

$$(x + \frac{y}{4}) = \dots\dots\dots [1]$$

If you were unable to calculate values in (b)(i) and (b)(ii) then use the data in this box for the remaining parts of this question. These are **not** the correct values.

$$x = 6$$

$$(x + \frac{y}{4}) = 9$$

- (iii) Give the molecular formula and the empirical formula of **P**.

molecular formula of **P**

empirical formula of **P**

[2]

- (iv) **P** is unbranched.

Give the skeletal formulae for two possible structures of **P** that are positional isomers of each other.



[2]

- (v) Use the general gas equation to calculate the mass of **P** present in the original 25 cm³ gaseous sample, which was measured at 37 °C and 100 kPa.

Give your answer to **three** significant figures.

mass = ... g [3]

[Total: 11]

- 2** The halogens, chlorine, bromine and iodine, and their compounds, show a variety of similarities and trends in their physical and chemical properties.

- (a) (i)** Give the colours and states of chlorine, bromine and iodine at room temperature and pressure.

halogen	colour	state
chlorine		
bromine		
iodine		

[2]

- (ii)** The halogens become less volatile down the group.

Explain this trend in volatility.

.....

 [2]

- (b)** The halogens are oxidising agents.

State and explain the trend in oxidising power of the halogens.

.....

 [3]

- (c)** Concentrated sulfuric acid reacts with solid sodium halides.

- (i)** State any observations that would be made on addition of concentrated sulfuric acid to

- solid sodium chloride, ...

- solid sodium iodide.
 [2]

- (ii) Give reasons for the difference in the observations in (i).

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

- (iii) The addition of concentrated sulfuric acid to solid sodium bromide, NaBr, produces brown fumes and an acidic gas that decolourises acidified potassium manganate(VII) solution. This acidic gas is a significant contributor to acid rain.

Write the equation for the reaction of concentrated sulfuric acid with sodium bromide.

..... [2]

- (d) An aqueous solution, **Z**, contains a mixture of sodium chloride and sodium iodide.

- (i) Excess aqueous silver nitrate is added to **Z** in a test-tube. A yellow precipitate forms.

Explain the colour of this precipitate.

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

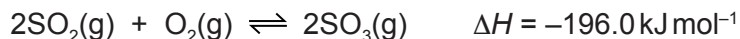
- (ii) Aqueous ammonia is then added to the test-tube in (i). The mass of precipitate decreases.

Explain this observation.

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

[Total: 15]

- 3 Sulfur trioxide, SO_3 , is manufactured from sulfur dioxide and oxygen by the Contact process.



- (a) The enthalpy change of formation of SO_2 , $\Delta H_f \text{SO}_2(\text{g})$, is $-296.8 \text{ kJ mol}^{-1}$.

- (i) Define the term *enthalpy change of formation*.

.....

 [2]

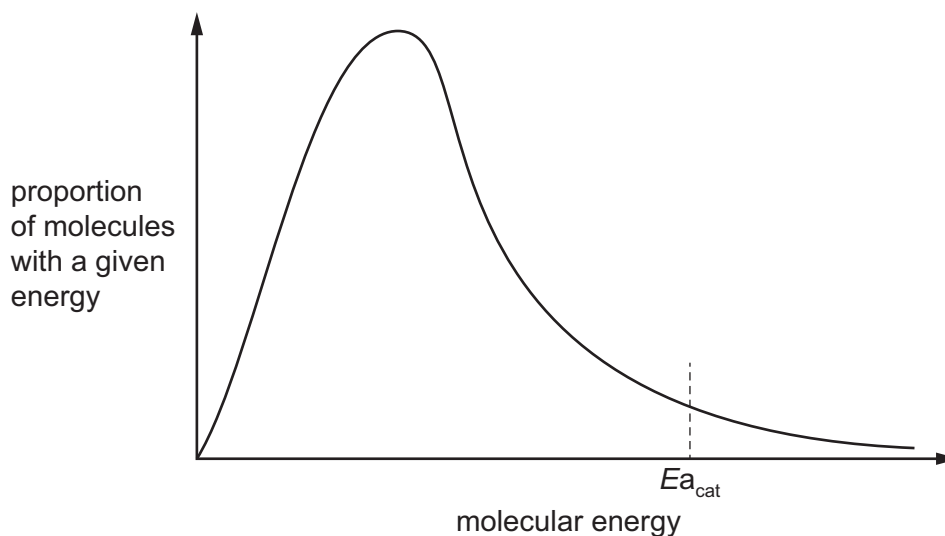
- (ii) Use the data to calculate the enthalpy change of formation of $\text{SO}_3(\text{g})$.

$$\Delta H_f \text{SO}_3(\text{g}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (b) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5 .

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.

$E_{a_{\text{cat}}}$ represents the activation energy for the reaction in the presence of the catalyst.



- (i) Add a labelled mark, $E_{a_{\text{uncat}}}$, to the diagram to indicate the activation energy in the absence of the catalyst. [1]

- (ii) State the benefit of using a catalyst in this reaction. Explain how it achieves this effect.

.....

.....

.....

..... [2]

- (iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate

.....

.....

.....

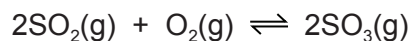
yield

.....

.....

..... [4]

- (c) At a pressure of $1.50 \times 10^5 \text{ Pa}$, 1.00 mol of sulfur dioxide gas, SO_2 , was mixed with 1.00 mol of oxygen gas, O_2 . The final equilibrium mixture formed was found to contain 0.505 mol of O_2 .



- (i) Calculate the amount, in mol, of SO_2 and SO_3 in the equilibrium mixture.

$\text{SO}_2 = \dots\dots\dots \text{ mol}$

$\text{SO}_3 = \dots\dots\dots \text{ mol}$
[1]

- (ii) Calculate the partial pressure of oxygen gas, p_{O_2} , in the equilibrium mixture.

$p_{\text{O}_2} = \dots\dots\dots \text{ Pa}$ [2]

- (d) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2 , the partial pressures of SO_2 , O_2 and SO_3 were as shown.

$$p\text{SO}_2 = 8.42 \times 10^2 \text{ Pa}$$

$$p\text{O}_2 = 6.00 \times 10^4 \text{ Pa}$$

$$p\text{SO}_3 = 9.10 \times 10^4 \text{ Pa}$$

- (i) Write the expression for the equilibrium constant, K_p , for the production of SO_3 from SO_2 and O_2 .

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction and state the units.

$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 17]

- 4 **A**, **B** and **C** all have the formula C_4H_8 . They all decolourise bromine and are structural isomers of each other.

(a) State the name of the process by which **A**, **B** and **C** could be obtained from $C_{10}H_{22}$.

..... [1]

(b) Draw the structures of these three **structural** isomers.



[1]

(c) Only **A** shows geometrical isomerism.

(i) Explain the meaning of the term *geometrical isomerism*.

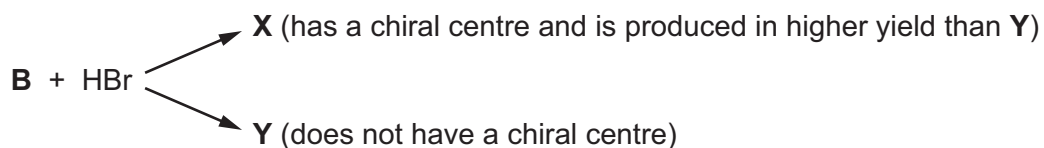
.....
.....
.....
..... [2]

(ii) Draw the displayed formula of **A** and use it to show the mechanism of the reaction of **A** with HBr. Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

(d) **B** does **not** show geometrical isomerism.

B reacts with HBr to form a mixture of two structural isomers, **X** and **Y**.



(i) State the meaning of the term *chiral centre*.

.....

.....

.....

..... [1]

(ii) Name **B**.

..... [1]

(iii) **X** exists as a pair of optical isomers.

Draw these isomers using the conventional three-dimensional representation.

.....

[2]

(iv) Explain why **X** is produced in higher yield than **Y**.

.....

.....

.....

..... [2]

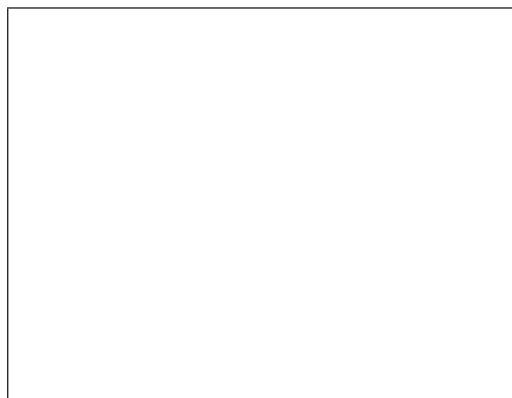
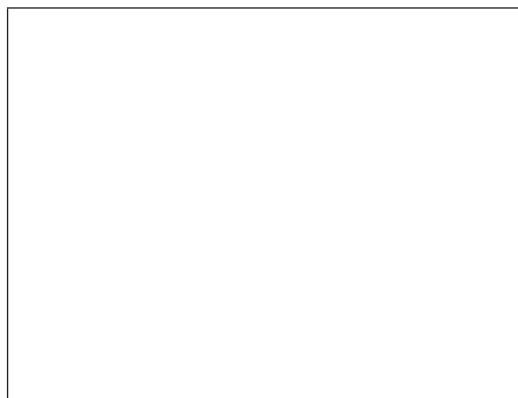
(e) **C** does **not** show geometrical isomerism.

C reacts with HBr to form a mixture of two structural isomers, neither of which has a chiral centre.

(i) Name **C**.

..... [1]

(ii) Draw the **displayed** formula of each of the structural isomers produced by the reaction of **C** with HBr.



[2]

[Total: 17]

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