

CANDIDATE
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CHEMISTRY

9701/21

Paper 2 Structured Questions AS Core

May/June 2015

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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The number of marks is given in brackets [] at the end of each question or part question.

This document consists of **11** printed pages and **1** blank page.

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

- 1 (a) Chemists recognise that atoms are made of three types of particle.

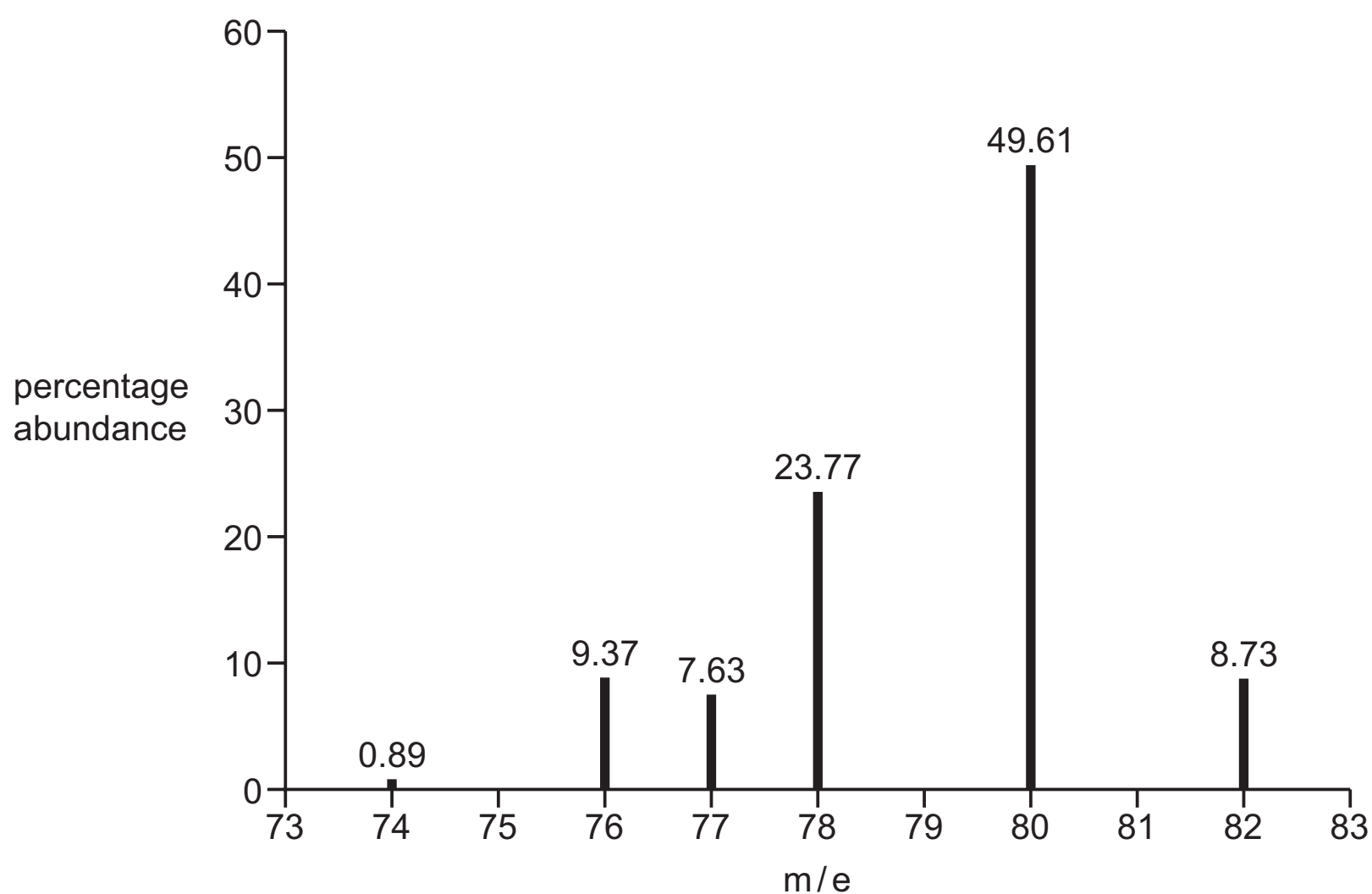
Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		0
	1/1836	

[3]

- (b) The relative atomic mass of an element can be determined using data from its mass spectrum.

The mass spectrum of element **X** is shown, with the percentage abundance of each isotope labelled.



- (i) Define the terms *relative atomic mass* and *isotope*.

relative atomic mass

.....

.....

isotope

.....

[3]

- (ii) Use the data in the mass spectrum to calculate the relative atomic mass, A_r , of **X**.
Give your answer to **two** decimal places and suggest the identity of **X**.

A_r of **X**

identity of **X**
[2]

- (c) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine by mass.

- (i) Calculate the molecular formula of this chloride.

molecular formula [3]

- (ii) This chloride melts at 224 °C and reacts vigorously with water.

State the type of bonding **and** structure present in this chloride and explain your reasoning.

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

- (iii) Suggest an equation for the reaction of this chloride with water.

..... [1]

(d) Sodium and silicon also react directly with chlorine to produce the chlorides shown.

chloride	melting point/°C	difference between the electronegativities of the elements
NaCl	801	2.2
SiCl ₄	−69	1.3

(i) Describe what you would **see** during the reaction between sodium and chlorine.

.....

.....

..... [2]

(ii) Explain the differences between the melting points of these two chlorides in terms of their structure **and** bonding. You should refer to the difference between the electronegativities of the elements in your answer.

NaCl structure **and** bonding

.....

SiCl₄ structure **and** bonding

.....

explanation

.....

.....

.....

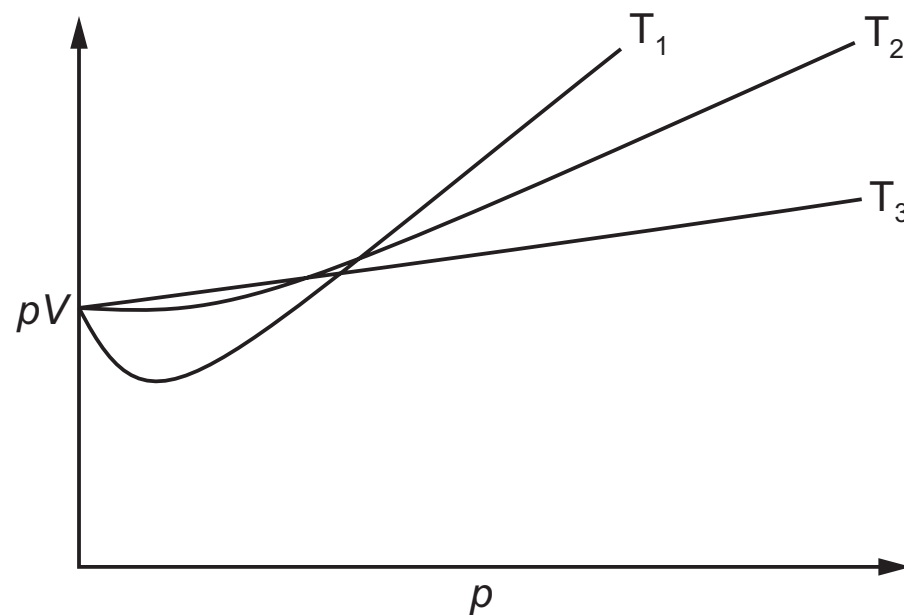
.....

..... [4]

[Total: 20]

2 The relationship $pV = nRT$ can be derived from the laws of mechanics by assuming ideal behaviour for gases.

(a) The graph represents the relationship between pV and p for a real gas at three different temperatures, T_1 , T_2 and T_3 .



(i) Draw **one** line on the graph to show what the relationship should be for the same amount of an **ideal** gas. [1]

(ii) State and explain, with reference to the graph, which of T_1 , T_2 or T_3 is the lowest temperature. [1]

..... [1]

(iii) Explain your answer to (ii) with reference to intermolecular forces. [1]

..... [1]

(iv) State and explain the effect of pressure on the extent to which a gas deviates from ideal behaviour. [2]

..... [2]

- (b) A flask with a volume of 100 cm^3 was first weighed with air filling the flask, and then with another gas, **Y**, filling the flask. The results, measured at 26°C and $1.00 \times 10^5\text{ Pa}$, are shown.

Mass of flask containing air = 47.930 g

Mass of flask containing **Y** = 47.989 g

Density of air = 0.00118 g cm^{-3}

Calculate the relative molecular mass, M_r , of **Y**.

M_r of **Y** = ... [4]

- (c) Although nitrogen gas makes up about 79% of the atmosphere it does not easily form compounds.

- (i) Explain why nitrogen is so unreactive.

.....
 [1]

- (ii) Explain why the conditions in a car engine lead to the production of oxides of nitrogen.

.....
 [1]

- (iii) Give an equation for a reaction involved in the removal of nitrogen monoxide, NO, from a car's exhaust gases, in the catalytic converter.

..... [1]

One of the main reasons for reducing the amounts of oxides of nitrogen in the atmosphere is their contribution to the formation of acid rain.

- (iv) Write an equation for the formation of nitric acid from nitrogen dioxide, NO_2 , in the atmosphere.

..... [1]

- (v) Write equations showing the catalytic role of nitrogen monoxide, NO , in the oxidation of atmospheric sulfur dioxide, SO_2 .

.....

..... [2]

[Total: 15]

- 3 Ethanal reacts with hydrogen cyanide, in the presence of a small amount of NaCN, as shown.



- (a) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign with your answer.

enthalpy change = ... kJ mol⁻¹ [3]

- (b) The product of this reaction shows stereoisomerism as it contains a chiral centre. This reaction produces an equimolar mixture of two optical isomers.

- (i) Explain the meanings of the terms *stereoisomerism* and *chiral centre*.

stereoisomerism

.....

.....

chiral centre

.....

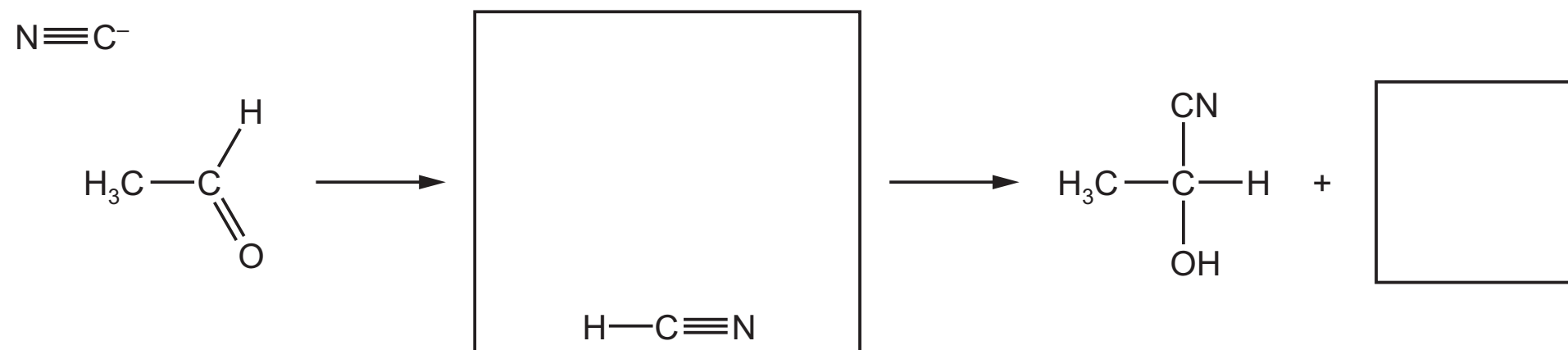
[2]

- (ii) Suggest why the two optical isomers are produced in equal amounts by this reaction.

.....

..... [1]

- (c) (i) Complete the diagram to show the mechanism of this reaction. Include all necessary charges, partial charges, lone pairs and curly arrows and show the structure of the intermediate.



[5]

- (ii) With reference to your mechanism in (i), explain the role of the NaCN in this reaction.

.....

..... [1]

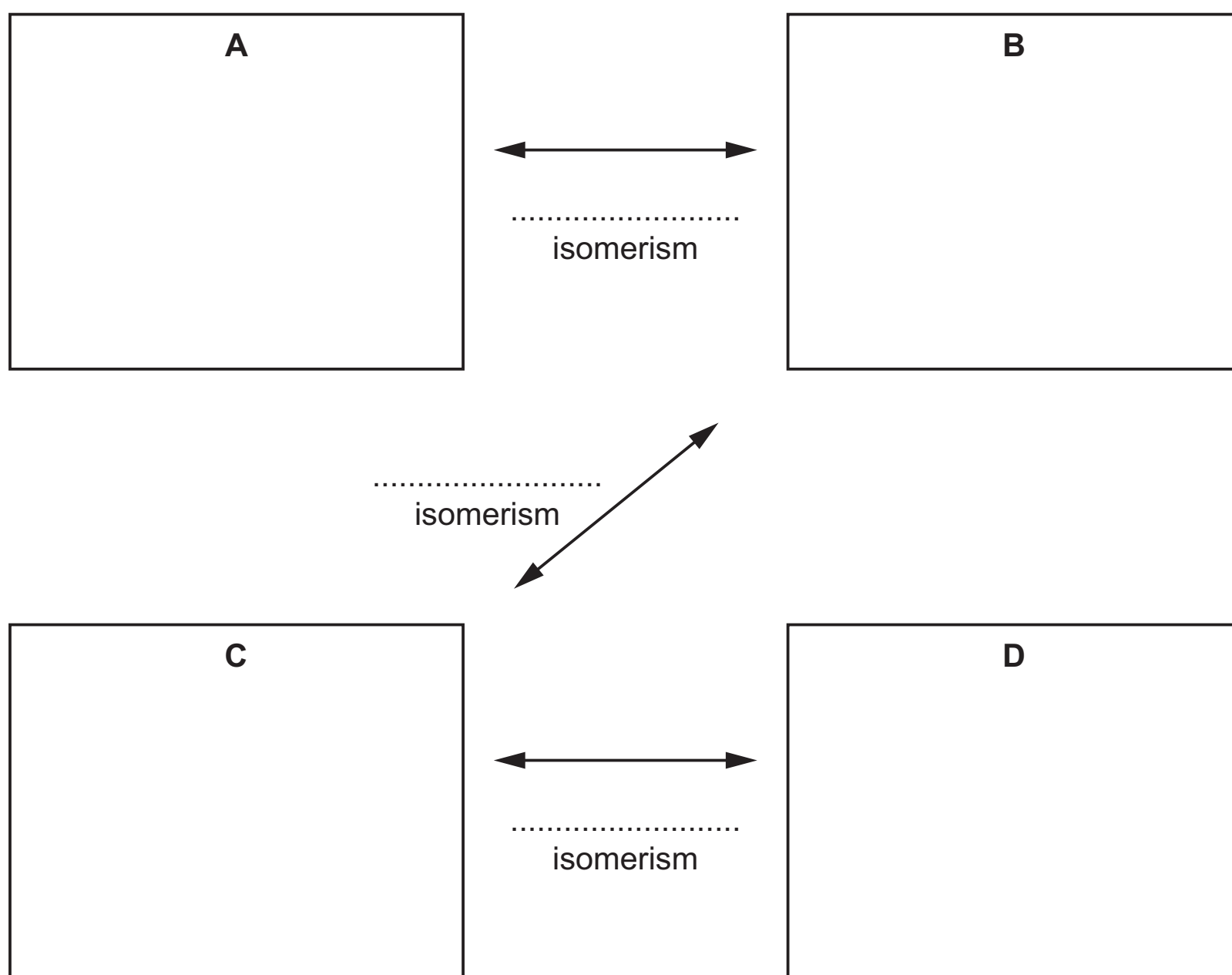
[Total: 12]

- 4 There are four alcohols, **A**, **B**, **C** and **D**, which are structural isomers with the molecular formula $C_4H_{10}O$.

Alcohol **A** does not react with acidified potassium dichromate(VI) solution but **B**, **C** and **D** do.

All four alcohols react with hot, concentrated sulfuric acid to form products with the molecular formula C_4H_8 . **A**, **C** and **D** each give a single product in this reaction. **B** gives a mixture of two structural isomers, one of which shows stereoisomerism.

- (a) Give the **skeletal** formula for each of the four alcohols and complete the diagram with the names of the types of structural isomerism shown by each linked pair of compounds.



[7]

- (b) (i) Give the names of the two structural isomers produced by the reaction of **B** with hot, concentrated sulfuric acid

..... [2]

- (ii) State which of these two isomers shows stereoisomerism. Explain why this molecule is capable of showing stereoisomerism.

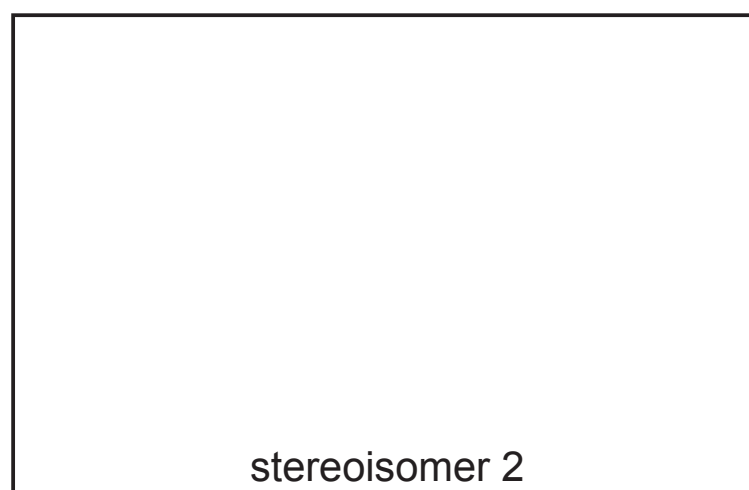
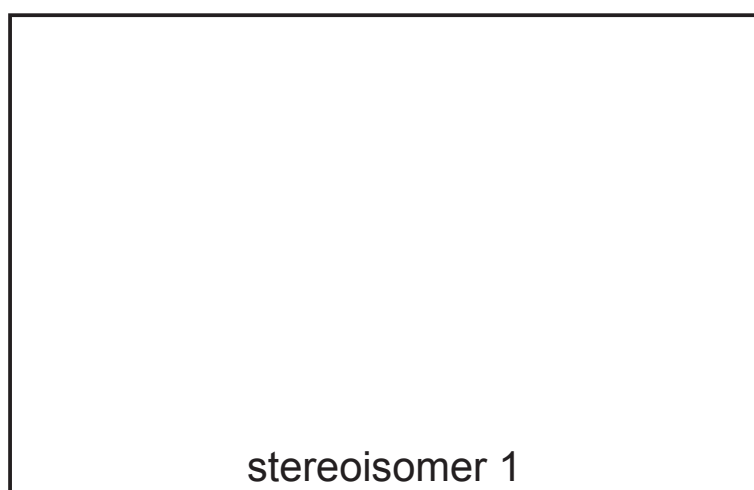
.....

.....

.....

..... [2]

- (iii) Draw **displayed** formulae to show the two stereoisomers.



[2]

[Total: 13]

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9701/22

May/June 2015

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Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		+1
	1/1836	

[3]

- (b) Most elements exist naturally as a mixture of isotopes, each with their own relative isotopic mass. The mass spectrum of an element reveals the abundances of these isotopes, which can be used to calculate the relative atomic mass of the element.

Magnesium has three stable isotopes. Information about two of these isotopes is given.

isotope	relative isotopic mass	percentage abundance
^{24}Mg	24.0	79.0
^{26}Mg	26.0	11.0

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

.....

 [2]

- (ii) The relative atomic mass of magnesium is 24.3.

Calculate the percentage abundance and hence the relative isotopic mass of the third isotope of magnesium. Give your answer to **three** significant figures

percentage abundance = ...

isotopic mass = ...

[3]

(c) Magnesium can be produced by electrolysis of magnesium chloride in a molten mixture of salts.

- (i) Give equations for the anode and cathode reactions during the electrolysis of molten magnesium chloride, MgCl_2 .

anode

cathode

[2]

The electrolysis is carried out under an atmosphere of hydrogen chloride gas to convert any magnesium oxide impurity into magnesium chloride.

- (ii) An investigation of the reaction between magnesium oxide and hydrogen chloride gas showed that an intermediate product was formed with the composition by mass Mg, 31.65%; O, 20.84%; H, 1.31% and Cl, 46.20%.

Calculate the empirical formula of this intermediate compound.

empirical formula [2]

(d) The acid/base behaviour of the oxides in the third period varies across the period.

- (i) Describe this behaviour and explain it with reference to the structure and bonding of sodium oxide, Na_2O , aluminium oxide, Al_2O_3 , and sulfur trioxide, SO_3 .

.....

.....

..... [2]

- (ii) Write equations for reactions of these three oxides with hydrochloric acid and/or sodium hydroxide as appropriate.

.....

.....

.....

..... [4]

[Total: 18]

2 Sulfuric acid is an important chemical with a variety of uses.

It is manufactured by the Contact process, the first stage of which involves the conversion of sulfur or a sulfide ore, such as galena, PbS, into sulfur dioxide, SO₂.

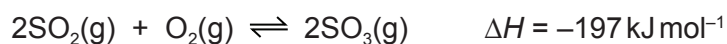
- (a) (i)** Write an equation for the reaction between galena and oxygen to form sulfur dioxide and lead(II) oxide.

..... [2]

- (ii)** Identify the oxidation number changes that take place during this reaction.

.....
 [2]

- (b)** The second stage of the Contact process involves the production of sulfur trioxide, SO₃, from sulfur dioxide.



- (i)** State the temperature usually chosen for this conversion and explain this in terms of reaction rates and Le Chatelier's principle.

temperature

explanation

.....

 [3]

- (ii)** State and explain the pressure conditions that would give the best rate and best yield of sulfur trioxide. Explain why these conditions are **not** actually used.

.....

 [3]

- (c)** In the third stage of the process the sulfur trioxide is dissolved in 98% sulfuric acid followed by carefully controlled addition of water.

- (i)** Explain why the sulfur trioxide is not dissolved directly in water to produce sulfuric acid.

.....
 [1]

- (ii) Write equations for the reaction of sulfur trioxide with sulfuric acid and for the subsequent reaction with water.

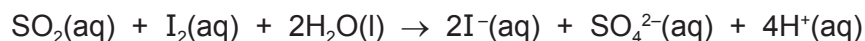
.....
 [2]

- (d) Explain why sulfur dioxide is used as an additive in some foods and wines.

.....

 [2]

- (e) The sulfur dioxide content of wine is most commonly measured by the Ripper Method which involves titration with iodine in the presence of starch as an indicator.



A 50.0 cm³ sample of wine required 12.35 cm³ of 0.010 mol dm⁻³ I₂(aq) for complete reaction with the SO₂.

- (i) How many moles of SO₂ are present in 50.0 cm³ of wine?

moles of SO₂ in 50.0 cm³ = ... [1]

- (ii) How many moles of SO₂ are present in 1 dm³ of wine?

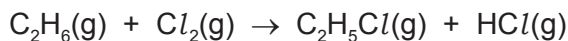
moles of SO₂ in 1 dm³ = ... [1]

- (iii) How many milligrams, mg, of SO₂ are present in 1 dm³ of wine? Give your answer to **three** significant figures. (1 g = 1000 mg)

mass of SO₂ in 1 dm³ = ... mg [1]

[Total: 18]

- 3 Ethane reacts with chlorine to form chloroethane.



- (a) (i) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign in your answer.

enthalpy change = ... kJ mol⁻¹ [3]

- (ii) State the conditions needed for this reaction to occur.

..... [1]

- (iii) Use a series of equations to describe the mechanism of this reaction including the names of each stage and an indication of how butane can be produced as a minor by-product.

.....

 [5]

- (b) Chloroethane can be converted back into ethane by a two-stage process via an intermediate compound, **X**.



- (i) Give the name of **X**.

..... [1]

- (ii) Suggest the reagent and conditions needed for reaction 1.

..... [2]

- (iii) Suggest the reagent and conditions needed for reaction 2.

..... [1]

[Total: 13]

- 4 There are seven structural isomers with the molecular formula $C_5H_{10}O$ that are carbonyl compounds. Four of these are aldehydes.

These four aldehydes, **A**, **B**, **C** and **D**, have the following properties.

- Aldehyde **A** has a straight chain while **B**, **C** and **D** are branched.
- Aldehyde **B** is the only one of the four isomers with a chiral centre and it exists as a pair of optical isomers.
- Aldehyde **C** has two methyl groups in its structure but **D** has three.

(a) (i) Give the structure of each of the four isomers.

A	B
C	D

[4]

(ii) Draw the three-dimensional structures of the two optical isomers of **B**.

[2]

- (b) (i) Describe a chemical test that would allow you to distinguish between any of the four isomers **A** to **D** and any of the other three structural isomers of $C_5H_{10}O$, that are carbonyl compounds.

In your answer you should describe any necessary reagents and conditions as well as explaining what you would **see** in each case.

.....

.....

.....

.....

..... [3]

- (ii) Describe a test that would give the same result with all seven carbonyl isomers of $C_5H_{10}O$.

.....

.....

..... [2]

[Total: 11]

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

1 Neon is a noble gas.

(a) Complete the full electronic configuration of neon.

1s² [1]

(b) (i) Explain what is meant by the term *first ionisation energy*.

.....

 [3]

(ii) Explain why the first ionisation energy of neon is greater than that of fluorine.

.....
 [2]

(c) Neon has three stable isotopes.

isotope	mass number	percentage abundance
1		9.25
2	20	90.48
3	21	0.27

(i) Define the term *relative atomic mass*.

.....
 [2]

(ii) Use the relative atomic mass of neon, 20.2, to calculate the mass number of isotope 1.

mass number = ... [2]

- (d) A mixture of neon and argon has a mass of 0.275 g. The mixture was placed in a gas syringe at a temperature of 25 °C and a pressure of 100 kPa. Under these conditions the mixture was found to occupy a volume of 200 cm³.

(i) Calculate the average M_r of the mixture.

average M_r = ... [2]

- (ii) Use your answer to (i) to calculate the percentage of neon in the mixture.
Give your answer to **three** significant figures.

percentage of neon = ... % [1]

- (e) Neon and argon can both be obtained by fractional distillation of liquid air as they have different boiling points.

Neon has a boiling point of 27.3 K. The boiling point of argon is 87.4 K.

- (i) Name the force that has to be overcome in order to boil neon or argon and explain what causes it.

.....

 [3]

- (ii) Explain why argon has a higher boiling point than neon.

.....

 [2]

[Total: 18]

2 The elements in Group II, and their compounds, show a variety of trends in their properties.

(a) Magnesium, calcium and barium all react with cold water to form hydroxides.

(i) Describe and explain the trend in reactivity of these three elements with cold water.

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

(ii) Give the equation for the reaction of magnesium with cold water.

..... [1]

(iii) Suggest why the water eventually turns cloudy during the reaction of magnesium with cold water.

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

(iv) Suggest the equation for the reaction of hot magnesium with steam.

..... [1]

(b) The oxides of magnesium, calcium and barium all react with dilute nitric acid to form nitrates.

(i) Give the equation for the reaction of magnesium oxide with nitric acid.

..... [1]

(ii) State the trend in thermal stability of the nitrates of Group II.

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

(iii) Give the equation for the thermal decomposition of magnesium nitrate.

..... [1]

- (iv) Apart from lithium nitrate, the nitrates of the Group I elements decompose in a different way to those of the Group II elements.

The equation for the thermal decomposition of potassium nitrate is



By identifying any changes in oxidation number, explain which element is reduced and which is oxidised in this decomposition.

.....

 [3]

- (c) A refractory material is one that does not decompose or melt at very high temperatures. Over 50% of magnesium oxide production is for use as a refractory material.

Explain why magnesium oxide has a very high melting point.

.....

 [2]

- (d) The word 'lime' is usually used to refer to a range of calcium-containing compounds that have a range of uses.

- (i) Write equations to show how calcium carbonate can be converted into calcium hydroxide by a two-step process.

.....
 [2]

A garden pond, with a total volume of 8000dm^3 , has been contaminated in such a way that its pH has fallen to 4. This means that the concentration of hydrogen ions, H^+ , in the water is $1 \times 10^{-4}\text{mol dm}^{-3}$.

- (ii) Write an ionic equation for the neutralisation reaction that occurs between hydrogen ions and carbonate ions, CO_3^{2-} .

..... [1]

- (iii) Use your equation to calculate the mass of powdered calcium carbonate that would need to be added to the pond to neutralise the acidity.

mass = ... g [2]

[Total: 19]

3 **A, B, C, D, E** and **F** are all structural isomers with the molecular formula C_4H_8O .

(a) **A, B** and **C** all give an orange precipitate when treated with 2,4-DNPH but only **A** and **B** give a brick-red precipitate when warmed with Fehling's solution.

(i) Draw the **skeletal** formulae of **A, B** and **C**.

A	B	C

[3]

(ii) Name the type of structural isomerism shown by **A** and **B**.

..... [1]

(iii) State what you would **see** when a sample of **A** is warmed with Tollens' reagent.

..... [1]

(b) **D**, **E** and **F** all decolourise bromine and effervesce slowly with sodium metal.

E shows geometrical isomerism. Only **D** has a branched chain.

None of these isomers contains an oxygen atom bonded to a carbon atom involved in π bonding.

None of these isomers contains a chiral centre.

(i) Give the structures of **D**, **E** and **F**. Show the two stereoisomers of **E** and label the stereoisomerism shown.

D	
E 	E
F	

[5]

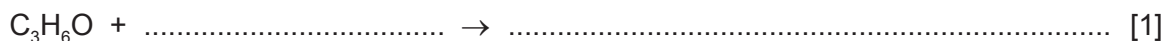
(ii) Identify the gas produced during the reaction of each of these isomers with sodium metal.

..... [1]

(c) Another compound, **G**, C_3H_6O , contains the same functional group as **A**.

Give equations for the reactions of **G** with each of acidified potassium dichromate(VI) and sodium tetrahydridoborate, $NaBH_4$, using [O] or [H] as appropriate.

(i) reaction with acidified potassium dichromate(VI)

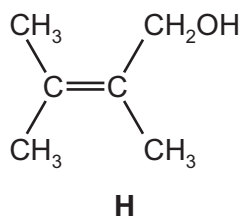


(ii) reaction with $NaBH_4$



[Total: 13]

4 The structure of **H** is shown.



(a) **H** reacts with both cold, dilute, acidified potassium manganate(VII) and with hot, concentrated, acidified potassium manganate(VII).

(i) Give the structure of the organic product of the reaction of **H** with cold, dilute, acidified potassium manganate(VII).

[1]

(ii) Give the structures of the organic products of the reaction of **H** with hot, concentrated, acidified potassium manganate(VII).

[2]

(b) (i) Complete the reaction scheme to show the mechanism of the reaction of **H** with bromine to form **J**.

Include all necessary curly arrows, lone pairs and charges.



[3]

(ii) Explain the origin of the dipole on the bromine molecule.

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

J is formed as an equimolar mixture of isomers.

(iii) State the type of isomerism shown by **J**.

..... [1]

(iv) Draw the structures of the two isomers of **J**.

[2]

[Total: 10]

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