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9701/21

May/June 2024

1 hour 15 minutes

No additional materials are needed.

- 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 and use appropriate units.

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

[Turn over

2

- 1 (a) The elements of Group 17 are called halogens.

Complete Table 1.1.

Table 1.1

halogen	colour at 293 K
chlorine	
bromine	
iodine	

[1]

- (b) State the trend in volatility of the halogens chlorine, bromine and iodine. Explain your answer.

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

- (c) Iodine is made by reacting bromine with sodium iodide.

- (i) Construct an ionic equation for the reaction of bromine with sodium iodide.

..... [1]

- (ii) State the role of bromine in the reaction. Explain your answer.

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

3

(d) Concentrated sulfuric acid is added to separate samples containing equal amounts of NaCl, NaBr and NaI. All three samples initially react to produce the hydrogen halide.

- (i)** Write an equation to describe the acid–base reaction that occurs when concentrated sulfuric acid reacts with NaBr.

..... [1]

- (ii)** Deduce which sodium halide, NaCl, NaBr or NaI, produces the largest percentage yield of hydrogen halide when concentrated sulfuric acid is added. Explain your answer by considering the relative reactivity of the halide ions as reducing agents.

identity of sodium halide

explanation

.....

.....

[3]

[Total: 10]

4

- 2 (a) Sulfur chloride, SCl_2 , is a liquid at room temperature. When SCl_2 is added to water, misty fumes are seen and a solution is made that turns universal indicator red.

(i) Identify the type of reaction that occurs when SCl_2 is added to water.

..... [1]

(ii) Name a chloride of a different Period 3 element that is also a liquid at room temperature and produces misty fumes when added to water.

..... [1]

(b) A molecule of SCl_2 contains two S–Cl covalent bonds.

(i) Complete the dot-and-cross diagram in Fig. 2.1 to show the arrangement of the outer electrons in a molecule of SCl_2 .

Use × to show electrons from the chlorine atoms.

Use • to show electrons from the sulfur atom.

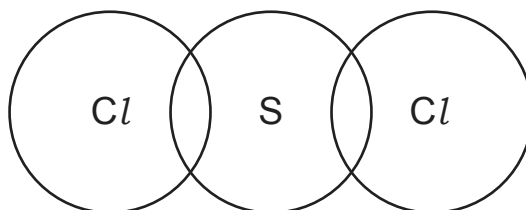


Fig. 2.1

[2]

(ii) Predict the shape of, and bond angle in, a molecule of SCl_2 by using VSEPR theory.

shape

bond angle

[2]

(c) Solid magnesium nitride, Mg_3N_2 , is a crystalline solid.

(i) Deduce the oxidation numbers of magnesium and nitrogen in magnesium nitride to complete Table 2.1.

Table 2.1

	oxidation number in Mg_3N_2
magnesium	
nitrogen	

[1]

5

- (ii) Magnesium nitride reacts with an excess of water to produce ammonia and magnesium hydroxide only. Construct an equation to describe this reaction.

..... [1]

- (iii) Explain why the solution produced in the reaction in (c)(ii) has a pH greater than 7. Refer to the products of the reaction in your answer.

.....

.....

..... [2]

- (d) Boron nitride is a white solid that melts above 2900 °C.

Fig. 2.2 shows part of the lattice structure of a crystal of boron nitride.

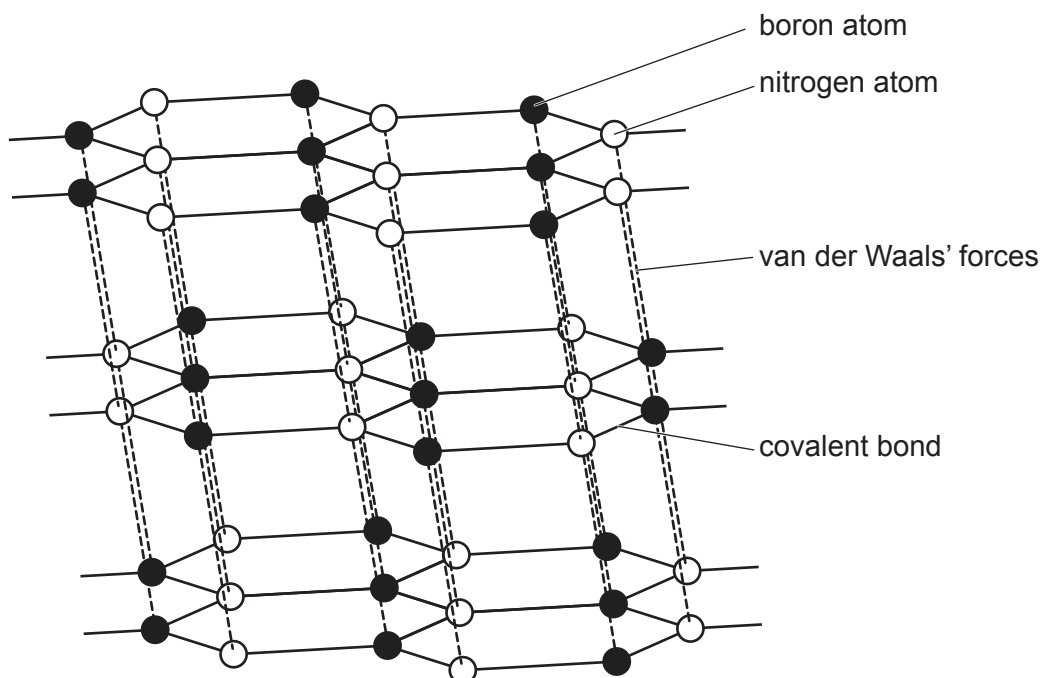


Fig. 2.2

- (i) Use Fig. 2.2 to deduce the empirical formula of boron nitride.

..... [1]

- (ii) Suggest the identity of another crystalline solid that has atoms arranged in layers similar to that of solid boron nitride.

..... [1]

[Total: 12]

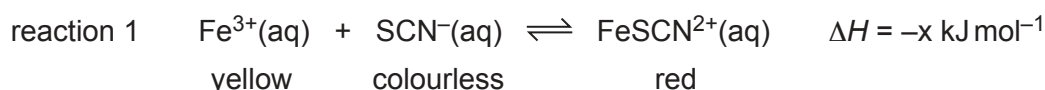
3 (a) Define Le Chatelier's principle.

.....

.....

..... [2]

(b) Reaction 1 describes the reversible reaction between yellow $\text{Fe}^{3+}(\text{aq})$ and colourless $\text{SCN}^{-}(\text{aq})$ to produce red $\text{FeSCN}^{2+}(\text{aq})$.



A mixture of $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{FeSCN}^{2+}(\text{aq})$ is at equilibrium at 20°C .

The temperature of this mixture is then increased to 50°C and allowed to reach equilibrium.

Deduce the changes that occur, if any, in the equilibrium mixture at 50°C compared to the equilibrium mixture at 20°C .

- change in appearance

.....

- change in relative concentration of $\text{FeSCN}^{2+}(\text{aq})$

.....

- change in value of the equilibrium constant, K_c

.....

[3]

7

- (c) In another experiment, equimolar amounts of $\text{Fe}^{3+}(\text{aq})$ and $\text{SCN}^{-}(\text{aq})$ are mixed together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3 .



At equilibrium the mixture contains:

- $[\text{SCN}^{-}] = 1.30 \times 10^{-3} \text{ mol dm}^{-3}$
- $[\text{FeSCN}^{2+}] = 0.300 \times 10^{-3} \text{ mol dm}^{-3}$.

- (i) Calculate the initial amount, in mol, of $\text{Fe}^{3+}(\text{aq})$ added to $\text{SCN}^{-}(\text{aq})$ to produce this mixture.

initial amount of $\text{Fe}^{3+}(\text{aq}) = \dots\dots\dots \text{ mol}$ [2]

- (ii) Calculate K_c for reaction 1 and state its units.

Show your working.

$K_c = \dots\dots\dots$

units $\dots\dots\dots$
[2]

[Total: 9]

4 (a) Define enthalpy change of formation.

.....

.....

..... [2]

(b) Iron is made when iron(III) oxide is heated with carbon monoxide, as shown by reaction 2.

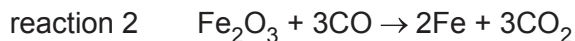


Table 4.1 shows enthalpy change of formation data measured at 298 K and 101 kPa.

Table 4.1

substance	equation	value for $\Delta H_f^\ominus / \text{kJ mol}^{-1}$
Fe_2O_3		−824.2
CO		−110.5
CO_2	$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	−393.5

(i) Complete Table 4.1 by adding equations with relevant state symbols to represent:

- standard enthalpy change of formation for Fe_2O_3
- standard enthalpy change of formation for CO.

[2]

(ii) Use the data in Table 4.1 to calculate the enthalpy change of reaction, ΔH_r , in kJ mol^{-1} , for reaction 2.

Show your working.

$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

[Total: 6]

5 Hydrocarbon molecules contain covalent bonds.**(a)** Define covalent bond.

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

(b) A C=C bond in an alkene is made from a σ bond and a π bond.**(i)** Identify the hybridisation of the carbon atoms in a C=C bond in an alkene.

..... [1]

(ii) Draw labelled diagrams to show, in terms of orbital overlap, how the σ and π bonds are made in a C=C bond. σ bond π bond

[2]

(c) In electrophilic reactions involving alkenes the π bond of C=C is broken.**(i)** Suggest **one** difference between σ and π bonds that explains why the π bond is broken in electrophilic addition reactions involving alkenes.

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

(ii) Complete Fig. 5.1 to show the mechanism for the electrophilic addition of hydrogen bromide to 2-methylpropene to produce the major organic product.

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

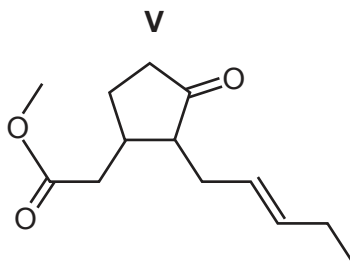
**Fig. 5.1**

[4]

[Total: 9]

10

- 6 (a) **V** shows stereoisomerism.



- (i) Explain what is meant by stereoisomerism.

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

- (ii) Deduce the number of stereoisomers of **V**. Explain your reasoning.

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

- (iii) Deduce the molecular formula of **V**.

..... [1]

- (iv) Name **all** the functional groups present in **V**.

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

11

(b) Fig. 6.2 shows two reactions involving **V**.

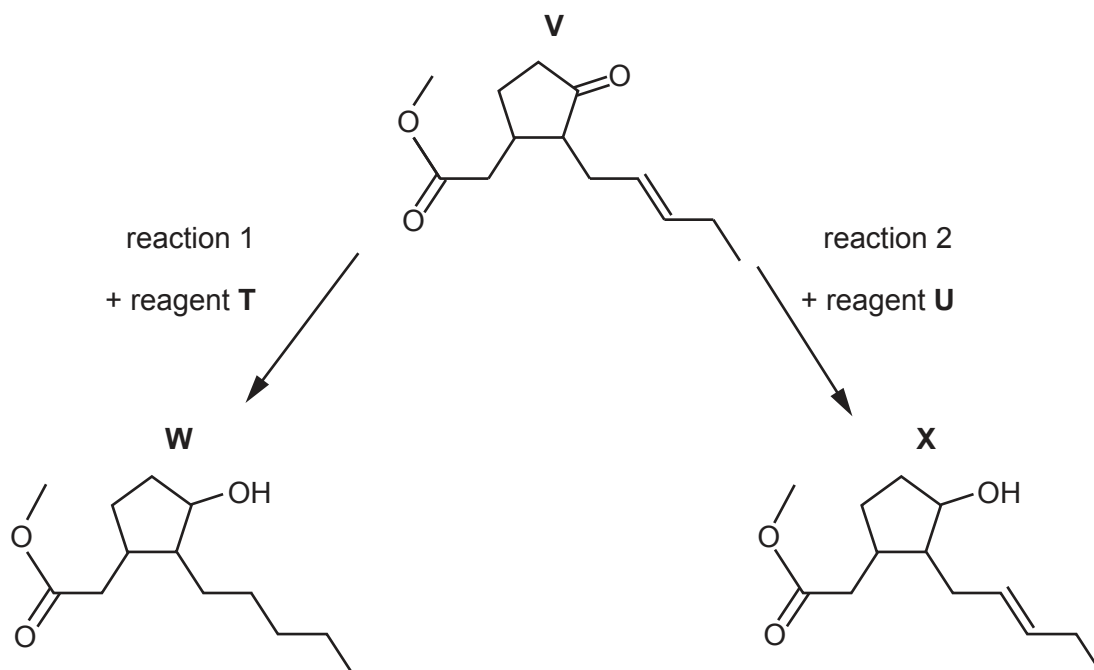


Fig. 6.2

(i) Identify the role of reagent **T** for each functional group that reacts in reaction 1.

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

(ii) Suggest the identity of reagent **U** in reaction 2.

..... [1]

12

- (c) Both functional groups in one molecule of **Y** react with an inorganic reagent to form one molecule of **Q** and one molecule of methanol, CH_3OH , as shown in Fig. 6.3.

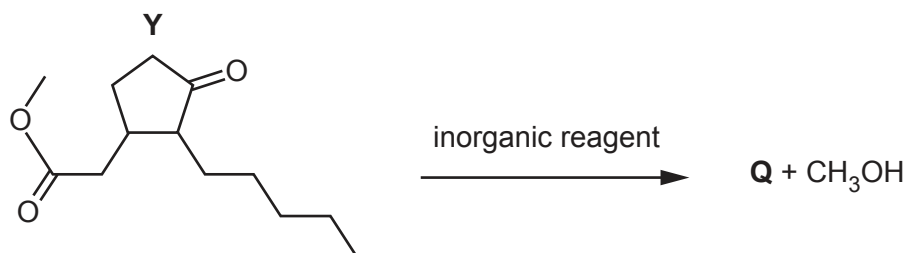


Fig. 6.3

- (i) Part of the mass spectrum for **Q** is shown in Fig. 6.4. Only peaks with m/e greater than 198 are shown.

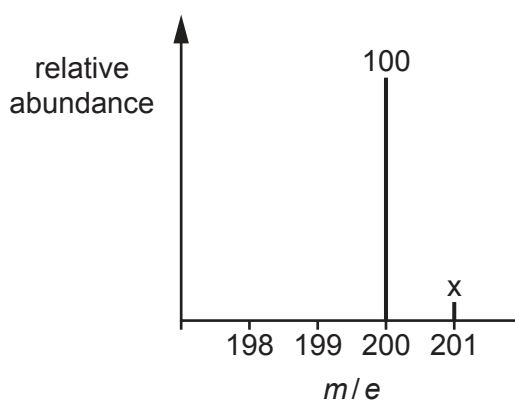


Fig. 6.4

Calculate the relative abundance, x , of the peak at $m/e = 201$.

Show your working.

$x = \dots\dots\dots$ [2]

- (ii) **Q** contains **only** hydroxyl functional groups.

Complete Table 6.1 to show the observations that occur when 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) is added to separate samples of **Y** and **Q**.

Table 6.1

	observation on addition of 2,4-DNPH reagent
Y	
Q	

13

- (iii) Under certain conditions, 0.0020 mol of **Q** reacts with an excess of sodium to produce a total of 44.8 cm³ of gas at s.t.p.

Calculate the number of hydroxyl groups present in a molecule of **Q**.

Show your working.

number of hydroxyl groups = [2]

- (iv) Use Table 6.2 to describe and explain **two** differences between the infrared spectrum of **Y** and **Q** in the region above 1500 cm⁻¹.

.....

.....

..... [2]

Table 6.2

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

[Total: 14]

14

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

Group																	
1	2		Key														
			atomic number atomic symbol name relative atomic mass														
3	Li	4	Be														
	lithium		beryllium														
	6.9		9.0														
11	Na	12	Mg														
	sodium		magnesium														
	23.0		24.3														
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co
	potassium		calcium		scandium		titanium		vanadium		chromium		manganese		iron		cobalt
	39.1		40.1		45.0		47.9		50.9		52.0		54.9		55.8		58.9
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh
	rubidium		strontium		yttrium		zirconium		niobium		molybdenum		technetium		ruthenium		rhodium
	85.5		87.6		88.9		91.2		92.9		95.9		—		101.1		102.9
55	Cs	56	Ba	lanthanoids													
	caesium		barium														
	132.9		137.3														
87	Fr	88	Ra	actinoids													
	francium		radium														
	—		—														

lanthanoids	57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu
		lanthanum		cerium		praseodymium		neodymium		promethium		samarium		europlum		gadolinium		terbium		dysprosium		holmium		erbium		thulium		ytterbium		lutetium
actinoids	89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr
		actinium		thorium		protactinium		uranium		neptunium		plutonium		americium		curium		berkelium		californium		einsteinium		fermium		mendeleevium		nobelium		lawrencium