Oxford Cambridge and RSA

A Level Chemistry B (Salters)

H433/01 Fundamentals of chemistry

Tuesday 13 June 2017 – Afternoon

Time allowed: 2 hours 15 minutes

You must have:
- the Data Sheet for Chemistry B (Salters) (sent with general stationery)

You may use:
- a scientific or graphical calculator

First name	
Last name	StemUp Model Solution

Centre number						Candidate number				

INSTRUCTIONS
- Use black ink. You may use an HB pencil for graphs and diagrams only.
- Complete the boxes above with your name, centre number and candidate number.
- Answer **all** the questions.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the barcodes.

INFORMATION
- The total mark for this paper is **110**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **32** pages.

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SECTION A

You should spend a maximum of 40 minutes on this section.

Answer **all** the questions.

Write your answer to each question in the box provided.

1 What is a possible mass number of a magnesium isotope?

A 12

B 23.99

C 24

D 24.3

Your answer C **[1]**

2 An element forms ions with a charge of 3+.

What could be the electron configuration of the atoms of the element?

A $1s^2 2s^2 2p^3$

B $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$

C $1s^2 2s^2 2p^6 3p^1$

D $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^3$

Your answer B **[1]**

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3 Some models of the structure of the atom are described below.

1 Atoms are spheres.

2 Atoms have a dense nucleus.

3 The electrons are arranged in shells.

4 Atoms have protons and electrons embedded in them.

Which row represents the historical sequence of these models, with the earliest first?

A	1	3	2	4
B	2	1	4	3
C	2	1	2	4
D	1	4	2	3

Your answer D **[1]**

4 Polymer **X** is –CH(OH)–CH($COOCH_3$)–CH(OH)–CH($COOCH_3$)–

What is the monomer of polymer **X**?

A CH(OH)–CH(COOH)

B C(OH)=C($COOCH_3$)–C(OH)=C($COOCH_3$)

C CH(OH)=CH($COOCH_3$)

D CH_2–CH(COOH)

Your answer C **[1]**

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5 An engine runs on ethanol.

What would **not** be found in the exhaust from this engine?

A SO_2

B CO_2

C NO

D CO

Your answer A **[1]**

6 Which statement about testing for nitrate(V) ions is correct?

A They give off ammonia gas when warmed with sodium hydroxide solution.

B Ammonia is detected because it turns blue litmus paper red.

C Aluminium is used to reduce nitrate(V).

D Nitrate(V) ions are oxidised.

Your answer C **[1]**

7 Which process is **not** oxidation?

A $NH_4^+ \rightarrow NO_2^-$

B $NO_3^- \rightarrow N_2$

C $N_2 \rightarrow NO$

D $NO_2^- \rightarrow NO_3^-$

Your answer B **[1]**

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8 Which statement about DNA is **not** true?

A DNA is a condensation polymer.

B Adenine and uracil join by 2 hydrogen bonds in DNA.

C Guanine and cytosine join by 3 hydrogen bonds in DNA.

D The backbone of DNA is made of phosphate and deoxyribose.

Your answer B **[1]**

9 Which statement describes the secondary structure of a protein?

A the types of amino acids present

B the sequence of the amino acids

C attractions between groups causing folding of the protein helix

D hydrogen bonds causing a helix or sheet

Your answer D **[1]**

10 A student is given the electrode potentials below.

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \qquad E^{\ominus} = +0.34\,V$$

$$Ag^+ + e^- \rightleftharpoons Ag \qquad E^{\ominus} = +0.80\,V$$

The student sets up a cell from the two half cells.

Which statement is correct?

A The cell voltage is 1.14 V.

B Cu^{2+} is reduced by Ag.

C Cu is oxidised by Ag^+.

D Cu^{2+} is oxidised by Ag.

Your answer C **[1]**

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11 Which ion is coloured?

A Zn^{2+}

B Sc^{3+}

C Ti^{3+}

D Ti^{4+}

Your answer C **[1]**

12 What describes a substance with a high retention time in gas-liquid chromatography?

A high volatility

B high solubility in the stationary phase

C high affinity for the mobile phase

D non-polar molecules

Your answer B **[1]**

13 What is the bond angle (in degrees) in the NH_2^- ion?

A 104.5°

B 107°

C 120°

D 180°

Your answer A **[1]**

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14 Why are many bond enthalpies described as *averages*?

A They are averaged out over many molecules with different kinetic energies.

B They are averaged out over different compounds containing the same bond.

C They are the averages of the bond in liquid and gaseous compounds.

D They are average values from different data books.

Your answer B **[1]**

15 Which statement is correct about *electronegativity*?

A It increases from left to right across a period.

B It increases down a group.

C It measures the negative charge on an atom.

D The smaller the electronegativity difference between two elements, the more likely the bond between them is ionic.

Your answer A **[1]**

16 Which one of these molecules has an overall dipole?

A CH_2F_2

B CF_4

C BF_3

D SF_6

Your answer A **[1]**

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17 Which row gives correct statements for both distillation and heating under reflux?

	Distillation	**Heating under reflux**
A	collects volatile product	collects involatile product
B	removes volatile product before further reaction	enables reaction to be heated for longer
C	enables reaction to be heated for longer	avoids fires from flammable products
D	collects involatile product	removes volatile product before further reaction

Your answer B **[1]**

18 What is correct about a mass spectrum of a compound?

A It shows the atoms produced from the compound.

B It enables the M_r of the compound to be determined.

C It has a small M+1 peak because of some ^2H atoms present in the compound.

D The units of the *x*-axis are 'mass'.

Your answer B **[1]**

19 Nitrogen dioxide reacts with carbon monoxide as in the equation below.

$$NO_2 + CO \rightarrow NO + CO_2$$

The mechanism is:

$$NO_2 + NO_2 \rightarrow NO + NO_3 \quad \text{Slow}$$
$$NO_3 + CO \rightarrow NO_2 + CO_2 \quad \text{Fast}$$

Which expression is the correct rate equation?

A Rate = $k\,[NO_2]\,[CO]$

B Rate = $k\,[NO_2]^2\,[CO]$

C Rate = $k\,[CO]$

D Rate = $k\,[NO_2]^2$

Your answer D **[1]**

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20 What is correct for reactions involving enzymes?

A The enzyme works best at high temperature.

B The rate is zero order with respect to substrate at low substrate concentration.

C The half-life for the substrate is always constant.

D The rate is zero order with respect to substrate at high substrate concentration.

Your answer D **[1]**

21 Which pair will **not** react together?

A $(CH_3)_3CCOCl$ and $(CH_3)_3CNH_2$

B CH_3COCl and CH_3OH

C $(CH_3)_3N$ and CH_3COCl

D C_6H_5OH and $(CH_3)_3CCOCl$

Your answer C **[1]**

22 What describes the first step in the nucleophilic substitution reaction of ammonia with a haloalkane?

A NH_3 attacks the halogen atom.

B NH_2^- attacks the carbon atom next to the halogen.

C NH_3 forms a bond with its lone pair to the carbon atom next to the halogen.

D The halogen atom is lost as a radical.

Your answer C **[1]**

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23 5.6 g of Fe (A_r = 56) and 4.0 g of S (A_r = 32) are heated in air until no further reaction occurs.

All the iron is converted to FeS and the rest of the sulfur forms SO_2.

What is the mass (in grams) of the sulfur dioxide formed?

A 1.6

B 4.0

C 8.0

D 10.4

Your answer A **[1]**

24 A student has 25 cm^3 of a 0.014 mol dm^{-3} solution.

How much water should be added to make the solution 0.010 mol dm^{-3}?

A 10 cm^3

B 14 cm^3

C 35 cm^3

D 49 cm^3

Your answer A **[1]**

25 The maximum solubility of magnesium hydroxide is 1.71×10^{-4} mol dm^{-3}.

What is the value of the solubility product?

A 5.00×10^{-12}

B 2.00×10^{-11}

C 2.92×10^{-8}

D 5.13×10^{-4}

Your answer B **[1]**

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26 What is the correct name of an isomer of pent-1-ene?

A cyclopentene

B pent-4-ene

C 1-methylbut-2-ene

D 3-methylbut-1-ene

Your answer D **[1]**

27 Which statement(s) connected with the greenhouse effect is/are correct?

1 The Earth radiates infrared radiation.

2 Solar energy heats the surface of the Earth.

3 Greenhouse gases absorb ultra violet radiation causing their bonds to vibrate more.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer B **[1]**

28 Which statement(s) about rusting is/are correct?

1 Rust contains Fe^{3+} ions.

2 Oxygen molecules are reduced during rusting.

3 The first step in rusting is $Fe \rightarrow Fe^{3+} + 3e^{-}$.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer B **[1]**

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29 Which statement(s) about the $[Fe(C_2O_4)_3]^{3-}$ ion is/are correct?

1 The bond angles around the metal are 90°.

2 The shape is octahedral.

3 The co-ordination number is 6.

A 1, 2 and 3

B Only 1 and 2

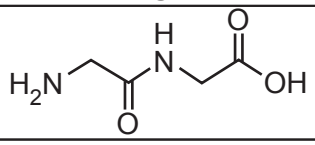
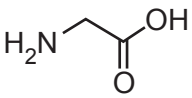
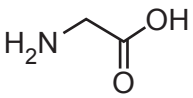
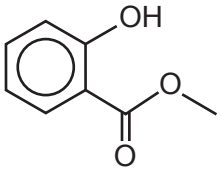
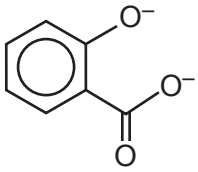
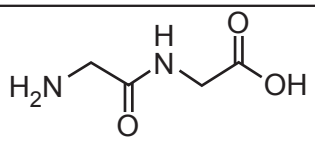
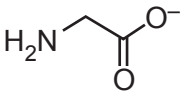
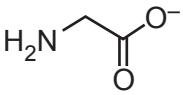
C Only 2 and 3

D Only 1

Your answer A **[1]**

30 Some organic reagents are hydrolysed under either acidic or alkaline conditions.

Which row(s) show(s) the correct products of the hydrolysis reactions?

	Reagent	Conditions	Product 1	Product 2
1		Acidic		
2		Alkaline		CH_3OH
3		Alkaline		

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer C **[1]**

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SECTION B

Answer **all** the questions.

31 Chlorine is manufactured by the electrolysis of sodium chloride solution.
The equation is shown below.

$$2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH.$$

(a) Give the half equation for the reaction at the negative electrode during electrolysis and explain why it is reduction.

Half-equation $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

(H_2O gains electrons: the oxidation state of H in H_2O decreases from +1 to 0 in H_2)

Explanation H is reduced: its oxidation state falls from +1 to 0. **[2]**

(b) A sodium chloride solution contains 24.0% of sodium chloride by mass.

1.0 tonne of this solution is electrolysed.

Calculate the mass of chlorine produced (in tonnes).
Give your answer to an **appropriate** number of significant figures.

mass of NaCl = 24.0% × 1.0 tonne = 0.240 tonne = 2.4×10^5 g

n(NaCl) = $2.4 \times 10^5 \div 58.5 = 4.10 \times 10^3$ mol

n(Cl_2) = $4.10 \times 10^3 \div 2 = 2.05 \times 10^3$ mol

mass of Cl_2 = $2.05 \times 10^3 \times 71.0 = 1.46 \times 10^5$ g = 0.15 tonnes

mass of chlorine = 0.15 tonnes **[3]**

(c) Industries using chlorine are often located close to the electrolysis plant.

Why is the transportation of chlorine dangerous?

Chlorine is toxic (poisonous), so a leak or accident during transport would endanger people nearby. **[1]**

(d) Chlorine reacts with alkanes to form chloroalkanes. This reaction begins with the formation of chlorine radicals.

(i) Complete the mechanism below to show the movement of electrons and name the type of bond fission.

Type of bond fission homolytic (fission) **[2]**

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(ii) Once the radicals have formed, they are highly reactive.
Give the equations for **two** propagation steps that occur in the reaction of ethane with chlorine.

$Cl\cdot + C_2H_6 \rightarrow HCl + C_2H_5\cdot$

$C_2H_5\cdot + Cl_2 \rightarrow C_2H_5Cl + Cl\cdot$

[2]

(iii) Chlorine radicals in the stratosphere act as homogeneous catalysts in the breakdown of ozone.

Give equations for the catalytic cycle.
Use the equations to explain the terms *homogeneous* and *catalyst*.

$Cl\cdot + O_3 \rightarrow ClO\cdot + O_2$

$ClO\cdot + O \rightarrow Cl\cdot + O_2$

overall: $O_3 + O \rightarrow 2O_2$

Homogeneous: the catalyst ($Cl\cdot$) and the reactants (O_3, O) are in the same (gas) phase.

Catalyst: $Cl\cdot$ is used up in step 1 but regenerated (reformed) in step 2, so it is unchanged at the end and is recycled to break down more ozone. **[3]**

(iv) Ozone is also broken down by radiation in the stratosphere.

$$O_3 \rightarrow O_2 + O$$

The bond broken in this reaction has a bond enthalpy of +302 kJ mol^{-1}.

Calculate the wavelength (in m) of radiation required to break this bond.

energy per bond, $E = 302\ 000 \div (6.02 \times 10^{23}) = 5.02 \times 10^{-19}$ J

$E = hc \div \lambda$, so $\lambda = hc \div E$

$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) \div (5.017 \times 10^{-19})$

$\lambda = 3.96 \times 10^{-7}$ m

wavelength = 3.96×10^{-7} m **[2]**

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(e) Hydrogen chloride can be prepared by reacting potassium chloride with concentrated sulfuric acid.

Give the equation for the reaction.

$H_2SO_4 + KCl \rightarrow KHSO_4 + HCl$

[1]

(f) The reaction in **(e)** is repeated with potassium iodide.
The hydrogen iodide formed is oxidised to iodine and the sulfuric acid is reduced to hydrogen sulfide.

Give the oxidation states of the elements in the compounds.

iodine in HI .....−1..... iodine in I_2 .....0.....

sulfur in H_2SO_4 .....+6..... sulfur in H_2S .....−2.....

Use these oxidation states to write a balanced equation for the reaction of HI with H_2SO_4.

Equation

S: +6 → −2, gains $8e^-$; I: −1 → 0, each I loses $1e^-$, so 8HI react with each H_2SO_4

$8HI + H_2SO_4 \rightarrow 4I_2 + H_2S + 4H_2O$

[3]

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32 One suggested method of carbon capture and storage is reacting carbon dioxide with naturally occurring metal oxides in the Earth's crust.

Magnesium oxide and calcium oxide could have formed when dolomite marble was subjected to high temperatures in the Earth.

(a) Dolomite contains both calcium and magnesium compounds.
A student says that magnesium and calcium have similar chemistry because they are close in the Periodic Table.

Comment on the student's statement.

Partly true: Mg and Ca are both in Group 2 (the same group), so they have the same number of outer electrons (2) and both lose 2 electrons to form 2+ ions when they react, giving similar chemistry. **[1]**

(b) A student finds that magnesium carbonate decomposes at a lower temperature than calcium carbonate.

Suggest the reason for this in terms of the ions present.

Mg^{2+} ions are smaller than Ca^{2+} (same charge), so have a higher charge density. So Mg^{2+} polarises (distorts) the carbonate ion more than Ca^{2+} does, so $MgCO_3$ breaks down more easily. **[2]**

(c) Calculate the volume of carbon dioxide (in dm^3) at 298 K and 95.0 kPa that could be captured by reacting it with 1.00 kg of MgO.

$MgO + CO_2 \rightarrow MgCO_3$ (1 mol MgO captures 1 mol CO_2)

$n(MgO) = 1000 \div 40.3 = 24.81$ mol $= n(CO_2)$

$pV = nRT$, so $V = nRT \div p$

$V = 24.81 \times 8.314 \times 298 \div 95\ 000 = 0.647\ m^3$

$V = 0.647 \times 1000 = 647\ dm^3$

volume = 647 dm^3 **[3]**

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(d)* Strontianite is a mineral first found in 1790. It contained a new element, strontium.

The element was first thought to be barium, which was known at the time.
However, strontium gave a red flame colour when heated and barium's flame is green.

Explain how elements can give off coloured light when heated and how analysis of the light from strontium proved that it was a new element.

When strontium is heated, its electrons absorb energy and are excited (promoted) from the ground state to higher energy levels.

The excited electrons then drop back down to lower energy levels, releasing the energy difference as electromagnetic radiation (light).

The energy levels are quantised (discrete), so each transition gives out a definite energy, $\Delta E = h\nu$, which is a particular frequency (wavelength) of light. Frequencies in the visible region are seen as colour.

This gives an emission spectrum of separate coloured lines; strontium emits mainly red frequencies, barium green.

Each element has its own unique set of energy levels and gaps between them, so its line spectrum is unique, like a fingerprint.

The light from strontium was analysed with a spectroscope and its line spectrum was compared with barium and all the other elements known at the time. It matched none of them, so it had to be a new element.

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

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(e) Strontianite may also contain small amounts of barium carbonate, lead carbonate or iron(II) carbonate.

Some students took separate samples of barium carbonate, lead carbonate and iron(II) carbonate and reacted them with nitric acid. They then devised tests on the resulting nitrate solutions that would show the presence of each metal ion and distinguish it from the other two.

Give three reagents they could use and the expected observations for each.
Within the table there must be a positive reaction for each ion.

Reagent solution	Observation for Ba^{2+}	Observation for Pb^{2+}	Observation for Fe^{2+}
dilute sulfuric acid, $H_2SO_4(aq)$	white precipitate	white precipitate	no reaction, stays a green solution
sodium hydroxide, $NaOH(aq)$	no reaction, colourless solution	white precipitate	green precipitate
potassium iodide, $KI(aq)$	no reaction, colourless solution	yellow precipitate	no reaction, stays a green solution

[3]

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33 An important source of hydrogen is from the steam reforming reaction shown below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g) \quad \Delta_r H = +206\,kJ\,mol^{-1}$$ **Equation 33.1**

(a) The position of equilibrium can be changed by altering the conditions.

Complete the table to show the effects on the yield of hydrogen and the value of the equilibrium constant, K_c.

	Increasing temperature	**Increasing pressure**
Effect on yield of hydrogen	*increases*	*decreases*
Effect on the value of K_c	*increases*	*no change*

[2]

(b) 2.00 moles of methane and 1.00 mole of steam are allowed to reach equilibrium in a 1.00 dm^3 container. At equilibrium 0.66 mole of steam remains.

Calculate a value for the equilibrium constant and give its units.

At equilibrium: 1.00 − 0.66 = 0.34 mol of H_2O has reacted

CH_4 = 2.00 − 0.34 = 1.66; H_2O = 0.66; CO = 0.34; H_2 = 3 × 0.34 = 1.02

(volume = 1.00 dm^3, so these are also the concentrations in mol dm^{-3})

$K_c = [H_2]^3[CO] \div ([CH_4][H_2O])$

$K_c = (1.02^3 \times 0.34) \div (1.66 \times 0.66) = 0.33$

K_c = ...*0.33*..... units ..*mol^2 dm^{-6}*..... **[3]**

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$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta_r H = +206\,kJ\,mol^{-1}$ **Equation 33.1**

(c) The entropy change for the forward reaction in **equation 33.1**, $\Delta_{sys}S = +214.5\,J\,K^{-1}\,mol^{-1}$.

(i) How does the sign of $\Delta_{sys}S$ relate to the equation for the reaction?

ΔS is positive (entropy increases) because there are more moles of gas on the right-hand side (4 mol of products) than on the left (2 mol of reactants). **[1]**

(ii) The entropy values for some of the gases in **equation 33.1** are shown below.

Gas	Entropy, S / $JK^{-1}mol^{-1}$
CH_4	+186.3
H_2O	+188.7
CO	+197.7

Use the value of $\Delta_{sys}S$ and the entropy values in the table to calculate the entropy of $H_2(g)$.

$\Delta_{sys}S = [3S(H_2) + S(CO)] - [S(CH_4) + S(H_2O)]$

$3S(H_2) = 214.5 + 186.3 + 188.7 - 197.7 = 391.8$

$S(H_2) = 391.8 \div 3 = +130.6\ J\ K^{-1}\ mol^{-1}$

entropy of $H_2(g)$ = +130.6 $J\,K^{-1}\,mol^{-1}$ **[2]**

(d) Calculate whether the forward reaction in **equation 33.1** is feasible at 1000 K.

$\Delta_{surr}S = -\Delta_r H \div T = -206\ 000 \div 1000 = -206\ J\ K^{-1}\ mol^{-1}$

$\Delta_{total}S = \Delta_{sys}S + \Delta_{surr}S = +214.5 + (-206)$

$\Delta_{total}S = +8.5\ J\ K^{-1}\ mol^{-1}$

$\Delta_{total}S$ is positive, so the forward reaction is feasible at 1000 K. **[2]**

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$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta_r H = +206\,kJ\,mol^{-1}$ **Equation 33.1**

(e) The steam reforming reaction shown in **equation 33.1** makes hydrogen.
Much of the hydrogen is used in the manufacture of ammonia.

(i) Calculate the atom economy of the reaction in **equation 33.1** when making hydrogen.

atom economy = (mass of $3H_2$ ÷ total mass of reactants) × 100

= (3 × 2.0) ÷ (16.0 + 18.0) × 100

= 6.0 ÷ 34.0 × 100 = 17.6%

atom economy = ...17.6..... % **[1]**

(ii) How is carbon monoxide described when it is formed alongside the required product (hydrogen)?

..It is a co-product.....

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

(f) The carbon monoxide can be used in the exothermic water gas shift reaction.

$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g)$ $\Delta_r H = -41\,kJ\,mol^{-1}$

The water gas shift reaction often takes place in the same industrial plant as steam reforming.

Suggest **two** advantages of the water gas shift reaction taking place with steam reforming.

1 ..It uses up (re-uses) the toxic CO, so the poisonous CO is not released.....
..into the air.....

2 ..The exothermic shift reaction releases heat, which can supply energy to.....
..the endothermic steam reforming, saving fuel.....

[2]

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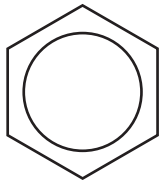
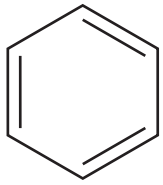
34 Two possible representations for benzene (C_6H_6) are shown below.

Structure 1	Structure 2
	

(a) **(i)** Compare and explain the bond angles and bond lengths predicted by each structure.

Bond angles Both structures predict bond angles of 120°.

In both, each carbon has three regions (areas) of electron density around it, which repel as far apart as possible: trigonal planar.

Bond lengths Structure 1: all six C–C bonds are the same length (delocalised ring).

Structure 2: the C=C bonds are shorter than the C–C bonds, so the bonds alternate short and long. **[4]**

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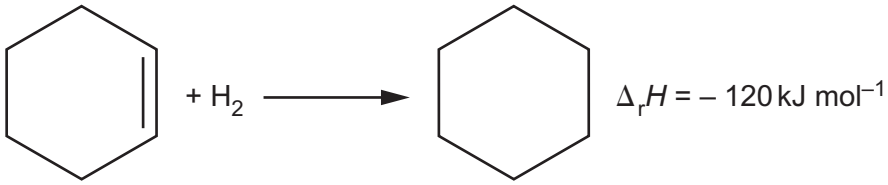
(ii) The equation below shows the hydrogenation of cyclohexene.

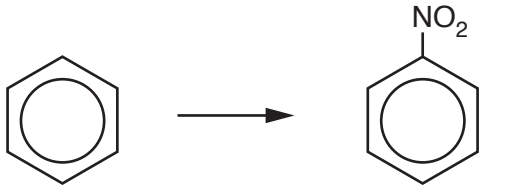


When benzene is reacted with hydrogen to form cyclohexane the enthalpy change is found to be $-208\,kJ\,mol^{-1}$.

Explain why this data supports structure **1** rather than structure **2**.

Structure 2 has three C=C bonds, so its hydrogenation would be expected to give $\Delta H = 3 \times (-120) = -360\ kJ\ mol^{-1}$. The actual value, $-208\ kJ\ mol^{-1}$, is much less exothermic (by 152 kJ mol^{-1}), so benzene is more stable than structure 2. This is because benzene has delocalised π electrons, as in structure 1, not three separate C=C bonds. **[2]**

(b) A student wants to synthesise a dye. The first step in the formation of the dye is shown below.



Benzene **Nitrobenzene**

(i) This is an electrophilic substitution reaction.

Give the conditions for the reaction and an equation to show how the electrophile is formed.

Conditions conc. HNO_3 and conc. H_2SO_4, below 55 °C

Equation for formation of the electrophile

$$HNO_3 + 2H_2SO_4 \rightarrow NO_2^+ + 2HSO_4^- + H_3O^+$$

[2]

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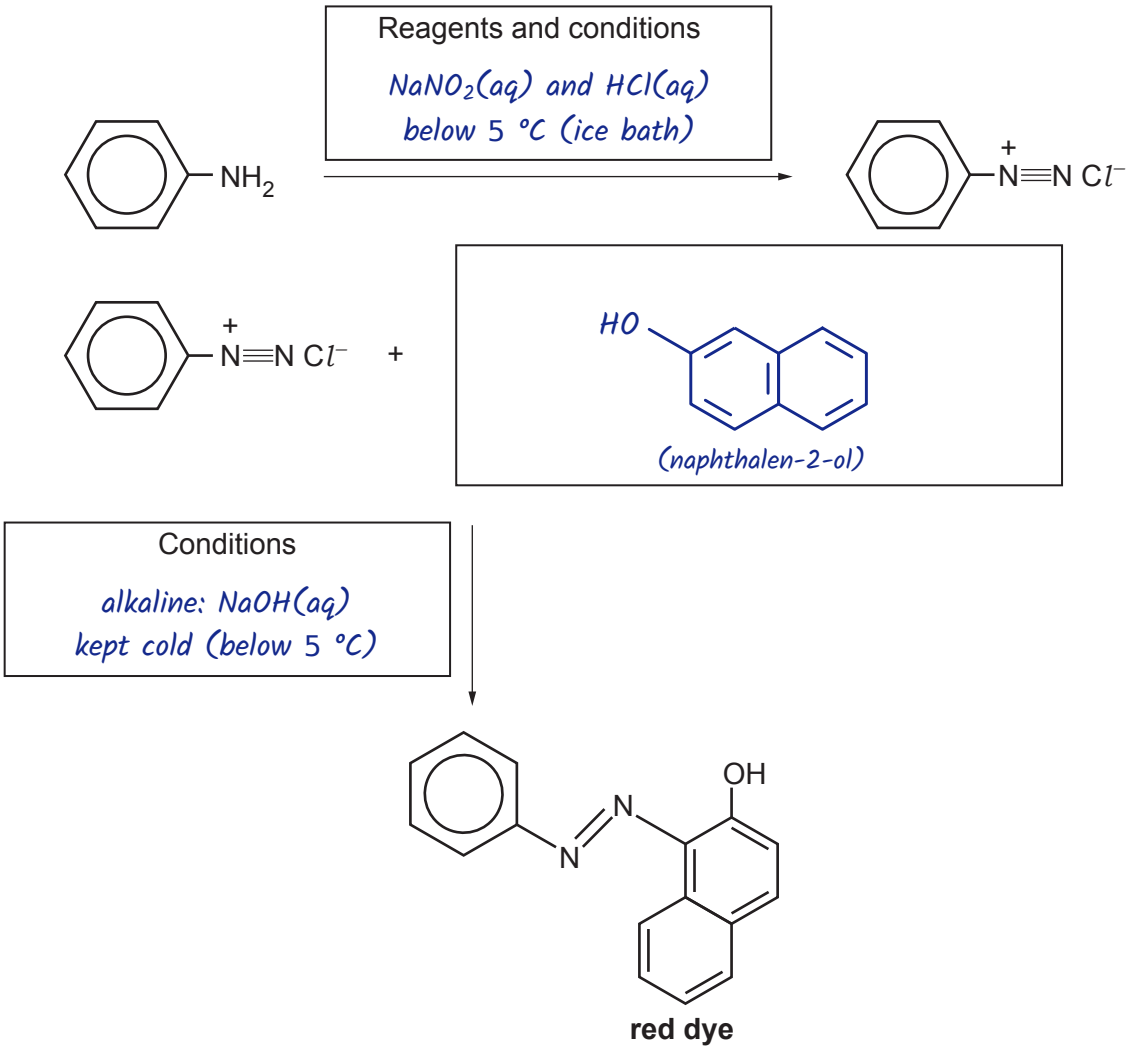
(ii) The nitrobenzene is then changed to phenylamine.

The flow diagram shows how the student could produce the red dye shown from phenylamine.

Complete the diagram by filling in the boxes.



red dye

[4]

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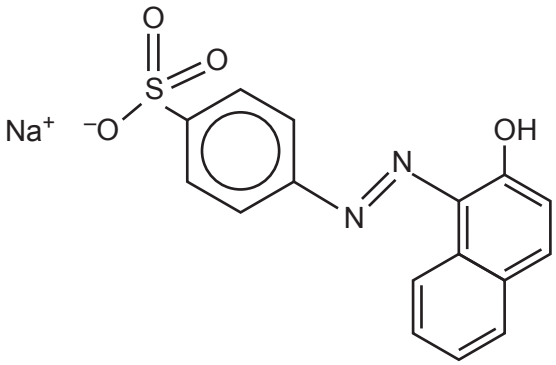
(c) The dye produced is not very soluble in water.
In order to increase its solubility it is converted to the structure below.



Name the $–SO_3^–$ group.

..(sodium)..sulfonate..group..... **[1]**

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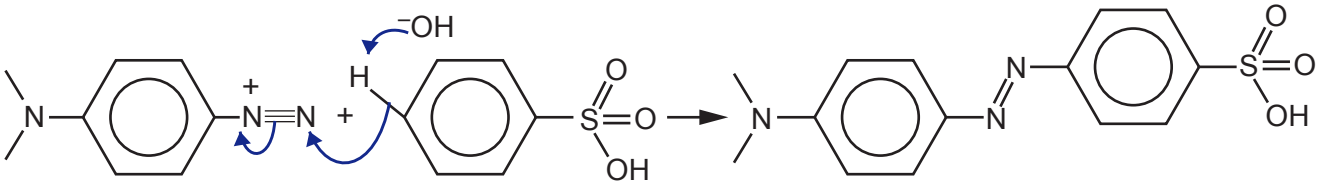
(d) Another dye is used as an acid-base indicator. It is red in acidic conditions and yellow in neutral or alkaline conditions.

The equation for the reaction producing the yellow form of the dye is shown below.
It is carried out in alkaline conditions.

Add curly arrows to the equation to show the mechanism of the reaction forming the dye.



yellow dye

[3]

(e) The indicator dye is a weak acid and may be described as HIn.
For the reaction shown below, $K_a = 1.6 \times 10^{-4}$ mol dm^{-3}.

$$HIn \rightleftharpoons H^+ + In^-$$

This indicator changes colour at pH 3.7.

Find the ratio $[In^-]$ / [HIn] when it changes colour.

$[H^+] = 10^{-pH} = 10^{-3.7} = 2.0 \times 10^{-4}$ mol dm^{-3}

$K_a = [H^+][In^-] \div [HIn]$, so $[In^-] \div [HIn] = K_a \div [H^+]$

$[In^-] \div [HIn] = 1.6 \times 10^{-4} \div 2.0 \times 10^{-4} = 0.80$

$[In^-]$ / [HIn] = ...0.80..... **[2]**

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35 Magnesium sulfate, $MgSO_4$, has a variety of uses in agriculture and in medicine.

It exists in the solid state as a hydrated salt, $MgSO_4 \cdot xH_2O$.

In order to find the value of *x* in the formula, a student follows the procedure below.

A known mass of magnesium sulfate crystals is dissolved in water. Aqueous sodium carbonate is added to precipitate magnesium carbonate, $MgCO_3$.

(a)* Describe how the student would use the results of the experiment to find a value for *x*. Suggest possible sources of inaccuracy and how they might be overcome.

Filter off the $MgCO_3$ precipitate, rinse it with distilled water, then dry it in a warm oven and weigh it.

$n(MgCO_3)$ = mass of ppt ÷ 84.3 = $n(MgSO_4)$ in the crystals (1 mol $MgSO_4$ gives 1 mol $MgCO_3$).

Mass of $MgSO_4$ = n × 120.4; mass of water = mass of crystals − mass of $MgSO_4$; $n(H_2O)$ = mass of water ÷ 18.0.

x = $n(H_2O)$ ÷ $n(MgSO_4)$, rounded to a whole number.

Inaccuracies: not enough Na_2CO_3 to precipitate all the Mg^{2+}, so add it in excess; ppt still wet, so dry it to constant mass; losses on filtering or pouring, so rinse all containers with distilled water and add the washings to the filter; not all the crystals dissolve, so use more water and stir.

[6]

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(b) The student looks up the enthalpy change of solution for anhydrous magnesium sulfate and finds it is $-84.00\,kJ\,mol^{-1}$.

The student measures the enthalpy change of solution of $MgSO_4{\bullet}7H_2O$ by adding it to water and measuring the temperature change.

The student's results are shown in the table.

Solute	Mass of solute dissolved / g	Mass of solution / g	Initial temperature of water / °C	Final temperature of water / °C
$MgSO_4{\bullet}7H_2O(s)$	9.7	50.0	18.0	15.0

Calculate $\Delta_{sol}H$ for $MgSO_4{\bullet}7H_2O$ in $kJ\,mol^{-1}$.
Assume the specific heat capacity of the solution is the same as that of water.

Use your answer, with the $\Delta_{sol}H$ for the anhydrous salt and draw an appropriate cycle to find a value for Δ_rH for the reaction shown below.

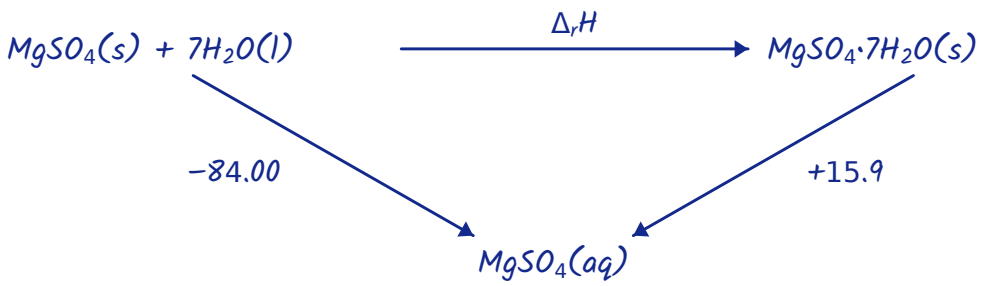
$$MgSO_4(s) + 7H_2O(l) \rightarrow MgSO_4{\bullet}7H_2O(s)$$

$q = mc\Delta T = 50.0 \times 4.18 \times 3.0 = 627\ J = 0.627\ kJ$

$M(MgSO_4{\cdot}7H_2O) = 24.3 + 32.1 + 64.0 + 7 \times 18.0 = 246.4\ g\ mol^{-1}$

$n = 9.7 \div 246.4 = 0.0394\ mol$

temperature falls, so endothermic: $\Delta_{sol}H = +0.627 \div 0.0394 = +15.9\ kJ\ mol^{-1}$



$\Delta_rH = -84.00 - (+15.9) = -99.9\ kJ\ mol^{-1}$

Δ_rH = ...−99.9.....$kJ\,mol^{-1}$ **[4]**

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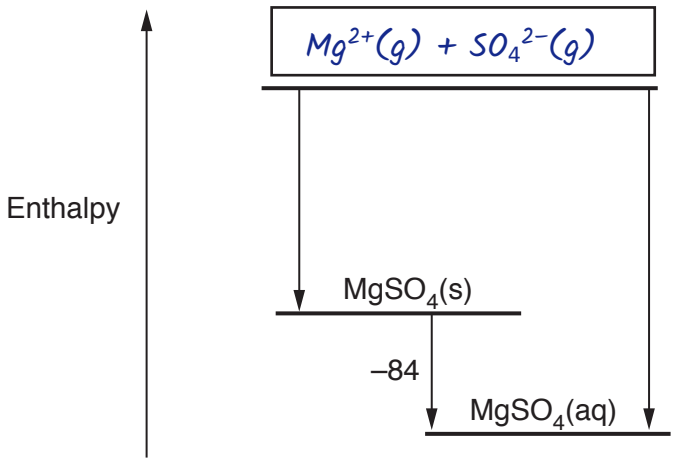
(c) $\Delta_{hyd}H$ values for the ions in magnesium sulfate are given in the table below.

Ion	$\Delta_{hyd}H$ / kJ mol^{-1}
Mg^{2+}	–1922
SO_4^{2-}	–1099

Fill in the missing species in the box and use the diagram to calculate $\Delta_{LE}H$ for magnesium sulfate.



$\Delta_{LE}H = \Delta_{hyd}H(Mg^{2+}) + \Delta_{hyd}H(SO_4^{2-}) - \Delta_{sol}H$

$\Delta_{LE}H = -1922 + (-1099) - (-84) = -2937$

$\Delta_{LE}H$ = ...–2937..... kJ mol^{-1} **[2]**

(d) Strontium sulfate is much less soluble than magnesium sulfate.

Use ideas of hydration enthalpy to suggest an explanation.

Sr^{2+} ions are larger than Mg^{2+} ions (same charge), so they have a lower charge density. So the ion–dipole attractions between Sr^{2+} and water are weaker: $\Delta_{hyd}H$ is less exothermic, so not enough energy is released to overcome the lattice enthalpy (so less dissolves). **[2]**

END OF QUESTION PAPER

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ADDITIONAL ANSWER SPACE

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