Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A410U10-1

S24-A410U10-1

MONDAY, 10 JUNE 2024 – MORNING

CHEMISTRY – A level component 1

Physical and Inorganic Chemistry

2 hours 30 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 8.**	**15**	
Section B	**9.**	**15**	
	10.	**16**	
	11.	**18**	
	12.	**13**	
	13.	**14**	
	14.	**13**	
	15.	**16**	
	Total	**120**	

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01

ADDITIONAL MATERIALS

- A calculator, pencil and ruler
- **Data Booklet** supplied by WJEC

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.
Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

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

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q11**(d) and **Q14**(a).

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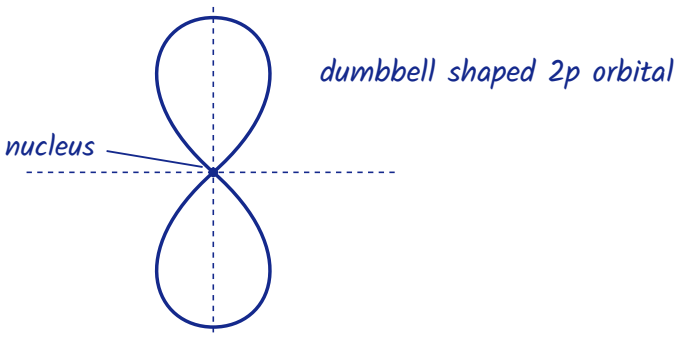
SECTION A

Answer **all** questions.

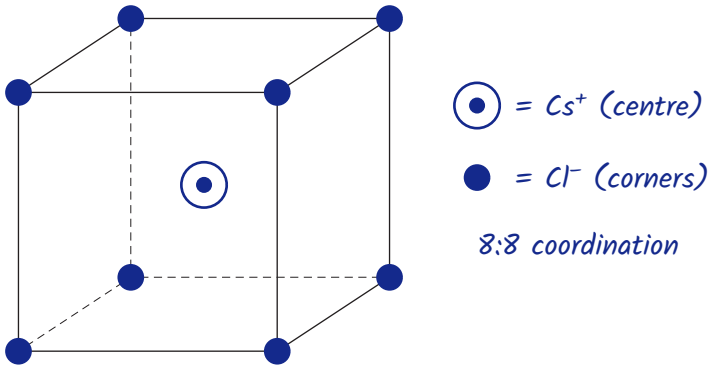
1. (a) Write the electronic structure of the Na^+ ion. [1]

$1s^2\ 2s^2\ 2p^6$

(b) Draw the shape of the orbital that contains the outermost electron of the Na^+ ion. [1]



2. (a) Draw the arrangement of ions in the structure of CsCl. Differentiate clearly between Cs^+ and Cl^- ions. [1]



(b) Explain why CsCl conducts electricity when molten but not when solid. [1]

Molten: the ions are free to move and carry charge. Solid: the ions are held in fixed positions in the lattice so cannot move.

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3. Nitrogen and phosphorus can both form chlorides of formula XCl_3 but only phosphorus can form a chloride of formula XCl_5.

Explain why PCl_5 exists but NCl_5 does not. [2]

Phosphorus (period 3) has available empty 3d orbitals, so it can expand its octet and use all five outer electrons to form five P–Cl bonds. Nitrogen (period 2) has no d-orbitals available, so it cannot expand its octet beyond 8 electrons and forms only three bonds.

4. Cyclohexene reacts with aqueous bromine to form the colourless compound 1,2-dibromocyclohexane.

(a) Suggest a method of measuring the rate of this reaction. [1]

Colorimetry: follow the decrease in absorbance (the orange bromine colour fading) against time using a colorimeter.

(b) The relative rate is measured using different concentrations of aqueous bromine and cyclohexene.

Use the results given in the table to find the rate equation for this reaction. [2]

Initial concentration of cyclohexene / mol dm^{-3}	Initial concentration of aqueous bromine / mol dm^{-3}	Relative rate
0.10	0.10	1
0.10	0.20	4
0.20	0.20	8

$[Br_2]$ doubles at constant $[C_6H_{10}]$: rate × 4, so 2nd order in Br_2

$[C_6H_{10}]$ doubles at constant $[Br_2]$: rate × 2, so 1st order in C_6H_{10}

rate = $k\,[C_6H_{10}]\,[Br_2]^2$

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5. 10.0 g of magnesium hydroxide is heated until it undergoes thermal decomposition.

Calculate the maximum mass of magnesium oxide that can be formed in this reaction. [2]

$Mg(OH)_2 \rightarrow MgO + H_2O$ (1 : 1)

moles $Mg(OH)_2 = 10.0 \div 58.32 = 0.171$ mol

mass of $MgO = 0.171 \times 40.3 = 6.91$ g

Mass = 6.91 g

6. Interhalogen compounds contain two types of halogen atom only.

In a mass spectrum the molecular ion of one interhalogen compound appears as two peaks, one at m/z 92 and another at m/z 94 in the height ratio 3:1.

Find the formula of this interhalogen compound. [2]

Two peaks 2 units apart in a 3:1 ratio: one Cl atom (^{35}Cl and ^{37}Cl)

remainder of $M_r = 92 - 35 = 57 = 3 \times 19.0$, so three F atoms

Formula ClF_3

7. State Le Chatelier's principle. [1]

When a system at equilibrium experiences a change in conditions, the position of equilibrium shifts to minimise (counteract) the change.

8. State the catalyst used in the contact process. [1]

vanadium(V) oxide, V_2O_5

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SECTION B

Answer **all** questions.

9. (a) Propanoic acid is a weak acid with a K_a of 1.34×10^{-5} mol dm^{-3} at 298 K.

(i) Propanoic acid can be neutralised using aqueous sodium hydroxide.

Calculate the pH of aqueous sodium hydroxide of concentration 0.500 mol dm^{-3}. [2]

$[H^+] = K_w \div [OH^-] = 1.00 \times 10^{-14} \div 0.500$

$= 2.0 \times 10^{-14}$ mol dm^{-3}

$pH = -\log (2.0 \times 10^{-14}) = 13.7$

pH = 13.7

(ii) 20.0 cm^3 of 0.500 mol dm^{-3} aqueous sodium hydroxide is added to 40.0 cm^3 of 0.500 mol dm^{-3} aqueous propanoic acid.

Calculate the pH of the resulting solution. [3]

moles NaOH = $0.500 \times 20.0 \div 1000 = 0.0100$ mol

moles acid = $0.500 \times 40.0 \div 1000 = 0.0200$ mol

half of the acid is converted to salt, so [acid] = [salt] (a buffer)

$[H^+] = K_a \times [acid] \div [salt] = K_a$, so $pH = pK_a$

$pH = -\log (1.34 \times 10^{-5}) = 4.87$

pH = 4.87

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(iii) Propanoic acid reacts with calcium carbonate in an endothermic reaction.

I. Complete the equation for this reaction. [2]

2 CH_3CH_2COOH + ... $CaCO_3$ ⟶ ..... H_2O + ... CO_2 + $(CH_3CH_2COO)_2Ca$

II. A student attempts to measure the enthalpy change of the reaction by following the method below.

- Measure 50.0 cm^3 of aqueous propanoic acid of concentration 0.200 mol dm^{-3} and place in a glass beaker. Measure the temperature.
- Add a lump of calcium carbonate of known mass. Measure the temperature.
- Calculate the difference between the two temperatures and calculate the enthalpy change for the reaction.

State and explain **three** changes needed to improve this method. [3]

Use a polystyrene (insulated) cup with a lid instead of a glass beaker, to reduce heat transfer from the surroundings.

Use powdered $CaCO_3$ instead of a lump and stir, so the reaction occurs quickly and completely.

Measure the temperature every 30 s for a few minutes before adding the $CaCO_3$ so the start temperature is constant, and every 30 s after adding it; plot temperature against time and extrapolate to allow for heat transfer from the environment.

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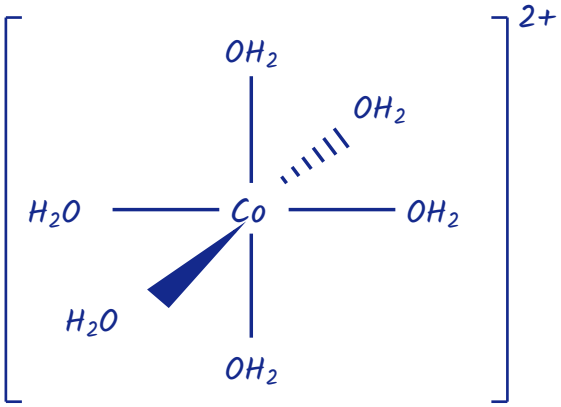
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(b) Transition metal ions in solution commonly form complex ions of formula $[M(H_2O)_6]^{n+}$. These can act as weak acids.

(i) Draw the structure of a $[Co(H_2O)_6]^{2+}$ ion. [1]



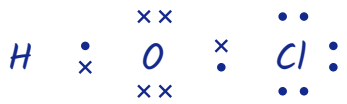
octahedral, 90°

(ii) State the colour of the $[Co(H_2O)_6]^{2+}$ ion. [1]

pink

(c) (i) HOCl is a weak acid that is formed when chlorine is added to water.

Draw a dot and cross diagram of this molecule. [1]



• = H or Cl electron × = O electron

(ii) Give the oxidation state of the chlorine atom in this molecule. [1]

+1

(iii) State the purpose of adding chlorine to water for public supply. [1]

To kill bacteria (disinfect the water).

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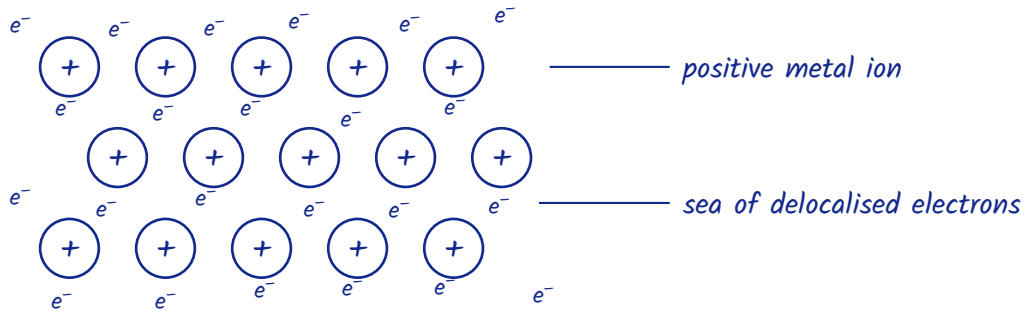
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10. Actinium, aluminium and americium are the first three elements alphabetically.

(a) These three elements are all metals. Explain how the structure of metals allows them to conduct electricity.

Include a diagram as part of your answer. [2]



Metals have a lattice of positive metal ions in a sea of delocalised electrons.

The delocalised electrons are free to move through the structure, so they carry charge when a potential difference is applied.

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(b) (i) The most stable isotope of actinium is ^{227}Ac. It can decay by emission of either an alpha or beta particle.

Identify the isotopes formed in each case. [2]

Product of alpha decay

Symbol Fr Mass number 223

Product of beta decay

Symbol Th Mass number 227

(ii) Naturally-occurring samples of actinium usually consist of mixtures of ^{227}Ac and ^{228}Ac. One sample has a relative atomic mass of 227.12.

Calculate the percentage of ^{227}Ac in this sample. [3]

Let x = % of ^{227}Ac

$A_r = [227x + 228(100 - x)] \div 100 = 227.12$

$22800 - x = 22712$

$x = 88$

Percentage of ^{227}Ac = 88 %

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(c) Aluminium is an amphoteric metal that produces electron-deficient compounds.

(i) Aluminium hydroxide is an amphoteric compound. Describe reactions that would show this amphoteric behaviour, including all relevant equations. [3]

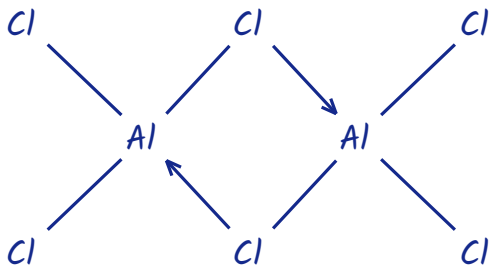
Aluminium hydroxide is amphoteric as it reacts with both acids and bases.

It dissolves in dilute acid: $Al(OH)_3 + 3H^+ \rightarrow Al^{3+} + 3H_2O$

It dissolves in excess NaOH(aq): $Al(OH)_3 + OH^- \rightarrow [Al(OH)_4]^-$

(ii) Explain why aluminium chloride molecules, $AlCl_3$, form dimers of formula Al_2Cl_6.

You may include a diagram as part of your answer. [3]



→ = coordinate bond (Cl lone pair donated to electron deficient Al)

In $AlCl_3$ the Al atom has only 6 outer shell electrons (fewer than 8), so it is electron deficient. Cl atoms have lone pairs; a lone pair on a Cl of one $AlCl_3$ forms a coordinate bond to the Al of another, giving Al_2Cl_6.

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(d) Americium-238 has a half-life of 98 minutes. It decomposes to form ^{238}Pu only. This plutonium isotope has a half-life of 88 years.

(i) A 10.0 mg sample of americium-238 is left for 294 minutes. Calculate the mass of plutonium present after 294 minutes. [2]

294 ÷ 98 = 3 half-lives

Am-238 left = 10.0 × $(1/2)^3$ = 1.25 mg

mass of ^{238}Pu formed = 10.0 − 1.25 = 8.75 mg

Mass = 8.75 mg

(ii) Suggest why it is important to know the half-life of the isotope formed when calculating the mass of plutonium. [1]

The Pu half-life (88 years) is much longer than 98 minutes / 294 minutes, so its decay does not affect the amount of Pu present; if it were short, some Pu would decay and the mass would be lower.

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11. Peroxynitrous acid, H — O — O — NO, is an isomer of nitric(V) acid, HNO_3.

(a) Peroxynitrous acid isomerises rapidly to form nitric acid with a rate constant of $4.52\,s^{-1}$ at a temperature of 37 °C.

(i) State the order of this reaction. Give a reason for your answer. [1]

First order: the rate constant has units of s^{-1}, which are the units for a first order reaction.

(ii) The frequency factor, *A*, for this reaction is $1.47 \times 10^9\,s^{-1}$.

Calculate the activation energy of the reaction. [3]

$k = Ae^{-Ea/RT}$ so $Ea = -RT \ln (k/A)$

$T = 37 + 273 = 310\ K$

$Ea = -8.31 \times 310 \times \ln (4.52 \div 1.47 \times 10^9)$

$= -8.31 \times 310 \times (-19.60) = 50\,490\ J\ mol^{-1}$

$= 50.5\ kJ\ mol^{-1}$

Activation energy = 50.5 $kJ\,mol^{-1}$

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(b) Peroxynitrous acid is an oxidising agent with a standard electrode potential of 1.42 V.

(i) State what is meant by the term standard electrode potential. [2]

The potential difference (emf) of a half-cell when it is connected to a standard hydrogen electrode, under standard conditions (298 K, 1 mol dm^{-3} solutions, 1 atm).

(ii) The table below shows the standard electrode potentials for some metal ions.

	Standard electrode potential, E^{θ}/V
$Co^{3+} + e^- \rightleftharpoons Co^{2+}$	+1.82
$Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$	+1.51
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	−0.41
$Ti^{3+} + e^- \rightleftharpoons Ti^{2+}$	−0.37

State which of the metal ions shown can be oxidised by peroxynitrous acid. Give your reasoning. [2]

Ti^{2+}, Cr^{2+} and Fe^{2+}.

$E^{\ominus}$ of peroxynitrous acid (+1.42 V) is more positive than $E^{\ominus}$ for the Ti^{3+}/Ti^{2+}, Cr^{3+}/Cr^{2+} and Fe^{3+}/Fe^{2+} half-cells, so it can oxidise these ions, but not Mn^{2+} or Co^{2+} ($E^{\ominus}$ more positive than +1.42 V).

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(c) Peroxynitrous acid is a weak acid with a K_a of 1.6×10^{-7} mol dm^{-3}. Nitric(V) acid is a strong acid.

Calculate the change in pH when a 0.100 mol dm^{-3} solution of peroxynitrous acid isomerises fully to form nitric(V) acid. [4]

Peroxynitrous acid: $[H^+] = \sqrt{(K_a \times [HA])} = \sqrt{(1.6 \times 10^{-7} \times 0.100)}$

$[H^+] = 1.26 \times 10^{-4}$ mol dm^{-3}

$pH = -\log (1.26 \times 10^{-4}) = 3.90$

Nitric(V) acid is strong: $[H^+] = 0.100$ mol dm^{-3}

$pH = -\log 0.100 = 1.00$

change in pH = $1.00 - 3.90 = -2.90$ (pH falls by 2.90)

Change in pH = −2.90

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(d) The concentration of a solution of nitric acid can be found by titration against a standard solution of sodium hydrogencarbonate, $NaHCO_3$.

$250.0\,cm^3$ of a standard solution of sodium hydrogencarbonate is made using 20.0 g of solid $NaHCO_3$.

Describe how this standard solution should be prepared and calculate its concentration.
[6 QER]

Weigh 20.0 g of solid $NaHCO_3$ accurately into a clean beaker.

Add a small volume of deionised water (about 100 cm^3, well below 250 cm^3) and stir with a glass rod until all of the solid has dissolved.

Transfer the solution into a 250.0 cm^3 volumetric (standard) flask using a funnel.

Rinse the beaker, glass rod and funnel with deionised water and add all the washings to the flask, so that no $NaHCO_3$ is lost.

Remove the funnel and add deionised water until the bottom of the meniscus is on the graduation mark (last drops with a dropping pipette, at eye level).

Put a stopper in the flask and invert it several times to mix thoroughly, so the solution has a uniform concentration.

moles $NaHCO_3$ = 20.0 ÷ 84.01 = 0.238 mol

concentration = 0.238 ÷ 0.250 = 0.952 mol dm^{-3}

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12. Chukanovite is an insoluble iron-containing mineral with a formula $Fe_a(OH)_b(CO_3)_c$.

A student performs a series of tests to analyse the mineral.

Number	Test	Results
1	Add 1.56×10^{-3} mol of the mineral to 25.0 cm^3 of 0.500 mol dm^{-3} nitric acid (an excess) and measure the volume of gas produced	37.2 cm^3 of gas was produced at a pressure of 1 atm and a temperature of 290 K
2	Titrate the remaining acid from test 1 against sodium hydroxide solution of concentration 0.300 mol dm^{-3}	Titration was repeated four times and the titres recorded were 20.55 cm^3, 20.95 cm^3, 20.90 cm^3 and 20.85 cm^3
3	Analyse the mineral to find its relative molecular mass	M_r was found to be 2.1×10^2 (to **two** significant figures)

(a) Calculate the value of **c**.

You **must** show your working. [3]

$p = 1\ atm = 1.01 \times 10^5\ Pa,\ \ V = 37.2\ cm^3 = 3.72 \times 10^{-5}\ m^3$

$n = pV \div RT = (1.01 \times 10^5 \times 3.72 \times 10^{-5}) \div (8.31 \times 290)$

$n(CO_2) = 1.56 \times 10^{-3}\ mol$ = moles of mineral, ratio 1 : 1

so each formula unit contains one CO_3^{2-}

c = 1

(b) Calculate the mean titre in test 2. [1]

concordant titres: (20.95 + 20.90 + 20.85) ÷ 3 (ignore 20.55)

Mean titre = 20.90 cm^3

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(c) The acid in test 1 reacts with all the carbonate ions and hydroxide ions.

Use the information provided in test 1 and test 2 to show that the value of **b** is 2. [4]

initial moles $HNO_3 = 0.500 \times 25.0 \div 1000 = 0.0125$ mol

moles $NaOH = 0.300 \times 20.90 \div 1000 = 6.27 \times 10^{-3}$ mol = moles acid left

moles acid reacting with mineral $= 0.0125 - 0.00627 = 6.23 \times 10^{-3}$ mol

acid : mineral $= 6.23 \times 10^{-3} \div 1.56 \times 10^{-3} = 4 : 1$

c = 1: $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$ uses 2 H^+

remaining 2 H^+ react 1 : 1 with OH^- ($H^+ + OH^- \rightarrow H_2O$)

so there are 2 OH^- per formula unit: b = 2

(d) Find the value of **a**. Use this and your answers to parts (a) and (c) to give the formula of chukanovite. [2]

mass from iron $\approx 210 - (2 \times 17.0) - 60.0 \approx 116$

number of Fe atoms $= 116 \div 55.8 \approx 2$, so a = 2

Formula $Fe_2(OH)_2(CO_3)$

(e) (i) Identify the oxidation state of the iron in chukanovite. Give a reason for your answer. [1]

+2: the 2 OH^- and 1 CO_3^{2-} give a total charge of −4, shared by 2 Fe, so each iron is Fe^{2+}.

(ii) Suggest a chemical test that could be used to confirm the oxidation state of the iron in chukanovite. [2]

Dissolve in acid (solution from test 1) and add aqueous sodium hydroxide: a green precipitate ($Fe(OH)_2$) forms.

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13. Nitrous oxide, N_2O, is a gas that can be part of several different gas phase equilibria. Two of these equilibria are shown below.

Equilibrium 1

$$2N_2O(g) + 3O_2(g) \rightleftharpoons 2N_2O_4(g) \qquad K_p = 1.57 \times 10^6\ Pa^{-3}$$

Equilibrium 2

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g) \qquad K_p = 1.24 \times 10^{-35}\ Pa^{-1}$$

(a) Use the words **high** or **low** to complete the sentences below. [1]

The concentration of N_2O in an equilibrium mixture formed for equilibrium 1 is

low

The concentration of N_2O in an equilibrium mixture formed for equilibrium 2 is

low

(b) Write an expression for K_p for equilibrium 2. Give its unit. [2]

$$K_p = \frac{p(N_2O)^2}{p(N_2)^2 \times p(O_2)}$$

Unit Pa^{-1}

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(c) A different equilibrium involving N_2O is shown below.

$$3NO(g) \rightleftharpoons N_2O(g) + NO_2(g)$$

A sample of NO at a total pressure of 1 atm was allowed to reach equilibrium and the mixture formed had a partial pressure of 8.9×10^{-4} Pa of NO.

Calculate the value of K_p for this reaction. [4]

initial p(NO) = 1 atm = 1.01×10^5 = 101 000 Pa

almost all the NO reacts (only 8.9×10^{-4} Pa left)

3 mol NO → 1 mol N_2O + 1 mol NO_2

$p(N_2O) = p(NO_2)$ = 101 000 ÷ 3 = 33 667 Pa

$K_p = p(N_2O) \times p(NO_2) \div p(NO)^3$

= $(33\,667 \times 33\,667) \div (8.9 \times 10^{-4})^3 = 1.61 \times 10^{18}$

K_p = *1.61×10^{18}* Pa^{-1}

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(d) Another method of producing oxides of nitrogen is by decomposition of metal nitrates, such as calcium nitrate.

$$2Ca(NO_3)_2(s) \longrightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$$

	Standard enthalpy change of formation, $\Delta_f H^\theta$ / kJ mol^{-1}	Standard entropy, S^θ / J K^{-1} mol^{-1}
$Ca(NO_3)_2(s)$	–937	193
$CaO(s)$	–635	40
$NO_2(g)$	34	240
$O_2(g)$	0	205

(i) Give a reason why the standard enthalpy change of formation for oxygen is 0 kJ mol^{-1}. [1]

Oxygen is an element in its standard state.

(ii) Calculate the standard enthalpy change for this reaction. [2]

$\Delta H = \Sigma \Delta_f H(products) - \Sigma \Delta_f H(reactants)$

$= [2(-635) + 4(34) + 0] - [2(-937)]$

$= -1134 + 1874 = +740$

$\Delta H^\theta =$ +740 kJ mol^{-1}

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(iii) Calculate the standard entropy change for this reaction. [2]

$\Delta S = [2(40) + 4(240) + 205] - [2(193)]$

$= 1245 - 386 = +859$

ΔS^{θ} = +859 $JK^{-1}mol^{-1}$

(iv) Calculate the minimum temperature required for this thermal decomposition. [2]

feasible when $\Delta G = \Delta H - T\Delta S \leq 0$, so $T = \Delta H \div \Delta S$

$T = 740\,000 \div 859 = 861$ K

$861 - 273 = 588$ °C

T = 588 °C

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14. (a) You are provided with six unlabelled solid mixtures.

A lead(II) nitrate and magnesium chloride
B magnesium chloride and barium chloride
C barium chloride and copper(II) nitrate
D copper(II) nitrate and lead(II) carbonate
E lead(II) carbonate and aluminium nitrate
F aluminium nitrate and lead(II) nitrate

You have access to common laboratory equipment and the following solutions.

- deionised water
- dilute nitric acid
- dilute hydrochloric acid
- aqueous sodium hydroxide

Suggest how you would identify which mixture is which. Give the observations expected for any tests you undertake. [6 QER]

Test 1: add deionised water to a sample of each mixture and shake. A, B, C and F dissolve completely; D and E do not fully dissolve (lead(II) carbonate is insoluble). C and D give a blue solution (Cu^{2+}), so C = soluble + blue, D = insoluble + blue, E = insoluble + colourless.

Test 2: flame test on A, B and F. B gives an apple-green flame (Ba^{2+}), so B is identified; A and F are inconclusive.

Test 3: add dilute nitric acid to D and E (not HCl, which would precipitate $PbCl_2$). Both effervesce (CO_2, turns limewater milky) and all the solid dissolves; D gives a blue solution, E a colourless solution, confirming D and E.

Test 4: dissolve each remaining mixture in dilute nitric acid and add aqueous sodium hydroxide dropwise. C gives a blue precipitate ($Cu(OH)_2$); D gives a mix of blue and white precipitates; A, E and F give white precipitates.

Test 5: add excess sodium hydroxide. The white precipitates from E and F redissolve completely ($Pb(OH)_2$ and $Al(OH)_3$ are amphoteric), whereas A only partly redissolves (white $Mg(OH)_2$ remains), which identifies F and A.

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(b) You are provided with a solution that is one of the following.

G aqueous sodium bromide

H a mixture of aqueous sodium chloride and aqueous sodium iodide

(i) Give the observations expected with these solutions when aqueous silver nitrate is added. [1]

Solution **G** *cream precipitate*

Solution **H** *cream precipitate (mixture of white and yellow)*

(ii) Give a further test that would allow you to confirm which of the two solutions you were given. [2]

Add concentrated ammonia solution to the precipitate. G: the cream precipitate dissolves completely. H: the precipitate only partially dissolves (AgCl dissolves, yellow AgI remains).

(c) Solution **J** contains iodide ions, $I^-(aq)$.

(i) State what is observed when aqueous lead(II) nitrate is added to solution **J**.

Give an ionic equation for the reaction. [2]

A (canary) yellow precipitate forms.

$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$

(ii) State what is observed when aqueous copper(II) sulfate is added to solution **J**.

Give an ionic equation for the reaction. [2]

A brown solution (iodine) with a white precipitate (CuI).

$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$

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15. (a) State what is meant by the term first ionisation energy. [1]

The energy needed to remove one electron (the outermost electron) from each atom in one mole of gaseous atoms, forming one mole of gaseous 1+ ions.

(b) The **second** ionisation energies of four elements are given below. The elements are lithium, magnesium, silicon and sodium but not in that order.

1450 kJ mol^{-1} 1580 kJ mol^{-1} 4560 kJ mol^{-1} 7300 kJ mol^{-1}

State which ionisation energy is associated with each element. Explain your choices. [5]

lithium *7300* kJ mol^{-1} magnesium *1450* kJ mol^{-1}

silicon *1580* kJ mol^{-1} sodium *4560* kJ mol^{-1}

Li and Na: the second electron is removed from an inner (full) shell, closer to the nucleus with less shielding, so their second IEs are much higher.

Li: the electron is in the innermost shell (1s) with no shielding, so Li has a higher IE than Na.

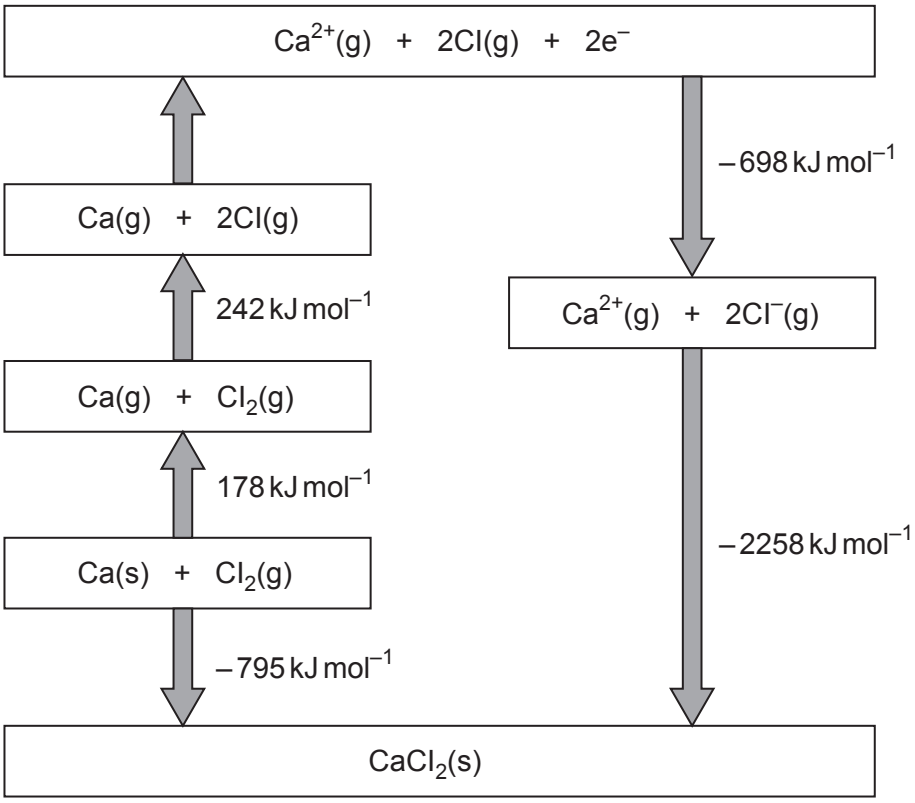
Mg and Si: the second electron comes from the outer shell; Si has a greater nuclear charge than Mg, so Si has the greater IE.

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(c) (i) Use the Born-Haber cycle to calculate the energy required to form a $Ca^{2+}(g)$ ion from a Ca(g) atom. [2]



$\Delta_f H = 178 + 242 + (IE_1 + IE_2) - 698 - 2258$

$-795 = (IE_1 + IE_2) - 2536$

$IE_1 + IE_2 = -795 + 2536 = 1741$

Energy required = 1741 $kJ\ mol^{-1}$

(ii) Suggest a value for the **first** ionisation energy of calcium. Give a reason for your answer. [1]

About 590 kJ mol^{-1}: the first ionisation energy must be smaller than the second, and the two add up to 1741 kJ mol^{-1}.

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(d) Most noble gases do not form compounds due to their very high ionisation energies. Amongst the very few noble gas compounds to form are XeF_2, XeF_4 and XeF_6.

(i) Although XeF_6 has six fluorine atoms bonded to the Xe atom, it does not have an octahedral shape. Explain why this is so. [2]

Xe has 8 outer electrons; 6 are used to bond to F, so there are seven electron pairs around Xe (six bonding pairs and one lone pair). An octahedral shape needs exactly six electron pairs; the lone pair repels more than the bonding pairs, so bond angles are less than 90°.

(ii) XeF_2 is soluble in anhydrous HF with a solubility of 162 g per 100 g of HF at 20 °C. The density of anhydrous HF is 1.66 g cm^{-3}.

Calculate the solubility of XeF_2 in HF at 20 °C in mol dm^{-3}. [3]

volume of 100 g HF = 100 ÷ 1.66 = 60.24 cm^3 = 60.24 × 10^{-3} dm^3

M_r XeF_2 = 131 + 2(19.0) = 169; moles = 162 ÷ 169 = 0.9586 mol

solubility = 0.9586 ÷ 60.24 × 10^{-3} = 15.9 mol dm^{-3}

Solubility = 15.9 mol dm^{-3}

(iii) The melting temperature of XeF_4 is 117 °C, whilst that of SiF_4 is –95 °C.

Explain why the melting temperature of SiF_4 is lower than that of XeF_4. [2]

SiF_4 has fewer electrons in a molecule than XeF_4, so there are weaker van der Waals (induced dipole) forces between SiF_4 molecules, which need less energy to overcome.

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