



Oxford Cambridge and RSA

Monday 13 June 2022 – Morning

A Level Chemistry A

H432/01 Periodic table, elements and physical chemistry

Time allowed: 2 hours 15 minutes

You must have:

- the Data Sheet for Chemistry A

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

--	--	--	--	--

Candidate number

--	--	--	--

First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **32** pages.

ADVICE

- Read each question carefully before you start your answer.

2
SECTION A

You should spend a maximum of 20 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

- 1** An aqueous solution contains a mixture of chloride, bromide and iodide ions.
 $\text{AgNO}_3(\text{aq})$ is added to this mixture, followed by an excess of dilute $\text{NH}_3(\text{aq})$.
The resulting mixture is then filtered.

Which compound(s) is/are present in the residue on the filter paper?

- A** AgCl only
B AgCl and AgBr
C AgBr only
D AgBr and AgI

Your answer

D

[1]

- 2** 20 cm^3 of nitrogen gas reacts with 10 cm^3 of oxygen gas to form 20 cm^3 of a gaseous product.
Which equation is the most likely for the reaction?

- A** $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$
B $\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{N}_2\text{O}_4(\text{g})$
C $2\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{N}_2\text{O}(\text{g})$
D $2\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g})$

Your answer

C

[1]

- 3 0.541 g of an element **X** is reacted with oxygen to form 0.790 g of the oxide **X₂O₃**.

What is the element **X**?

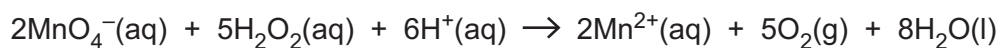
- A Al
- B Cr
- C Ga
- D Sc

Your answer

B

[1]

- 4 Hydrogen peroxide, H₂O₂, can be oxidised by manganate(VII) ions under acid conditions as shown below.



In a titration, 25.00 cm³ of a disinfectant containing hydrogen peroxide reacts with 22.00 cm³ of 0.125 mol dm⁻³ KMnO₄(aq).

What is the concentration of H₂O₂, in mol dm⁻³, in the disinfectant?
Assume that KMnO₄ only reacts with H₂O₂ in the disinfectant.

- A 0.0440
- B 0.110
- C 0.275
- D 0.550

Your answer

C

[1]

- 5 The mass of 4 molecules of a substance is 2.125×10^{-22} g.

What is the possible formula of the substance?

- A CH_4
- B O_2
- C SO_2
- D I_2

Your answer

B

[1]

- 6 Prussian blue, $\text{C}_{18}\text{Fe}_7\text{N}_{18}$, is a deep blue pigment containing Fe^{2+} , Fe^{3+} and CN^- ions.

What are the numbers of Fe^{2+} and Fe^{3+} ions in one formula unit of $\text{C}_{18}\text{Fe}_7\text{N}_{18}$?

- A 2 Fe^{2+} and 5 Fe^{3+}
- B 3 Fe^{2+} and 4 Fe^{3+}
- C 4 Fe^{2+} and 3 Fe^{3+}
- D 5 Fe^{2+} and 2 Fe^{3+}

Your answer

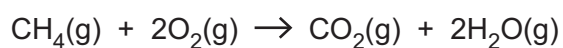
B

[1]

7 Bond enthalpies are shown in the table.

Bond	C–C	C–H	O–H	C–O	C=O	O–O	O=O
Bond enthalpy / kJ mol ⁻¹	347	435	464	358	805	144	498

What is the enthalpy change, in kJ mol⁻¹, for the reaction below?



A -730

B -544

C +544

D +730

Your answer

A

[1]

8 The half-life for a first order reaction is 80 s.

What is the rate constant k , in s⁻¹, for this reaction?

A 8.66×10^{-3}

B 0.0125

C 55.5

D 115

Your answer

A

[1]

- 9 Which equation represents the change that accompanies the standard enthalpy change of atomisation of bromine?

- A $\frac{1}{2} \text{Br}_2(\text{l}) \rightarrow \text{Br}(\text{g})$
 B $\text{Br}_2(\text{l}) \rightarrow 2\text{Br}(\text{g})$
 C $\frac{1}{2} \text{Br}_2(\text{g}) \rightarrow \text{Br}(\text{g})$
 D $\text{Br}_2(\text{g}) \rightarrow 2\text{Br}(\text{g})$

Your answer

A

[1]

- 10 For the condensation of ammonia gas, what are the signs of ΔH and ΔS ?

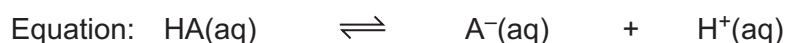
- A ΔH -ve ΔS -ve
 B ΔH -ve ΔS +ve
 C ΔH +ve ΔS +ve
 D ΔH +ve ΔS -ve

Your answer

A

[1]

- 11 The equilibrium equation for an indicator, HA, is shown below.



Colour: Blue Yellow

The indicator is added to a solution. The indicator turns a yellow colour.
 An excess of aqueous sodium hydroxide is then added.

Which statement describes how the colour of this solution would be expected to change?

- A Colour changes from yellow to blue.
 B Colour changes from yellow to green.
 C Colour changes from yellow to green and then to blue.
 D Colour stays yellow.

Your answer

D

[1]

- 12 Ammonia and water react to set up an acid–base equilibrium.

What are the Brønsted–Lowry acids in the equilibrium mixture?

- A H_2O and OH^-
- B OH^- and NH_3
- C NH_4^+ and H_2O
- D NH_4^+ and NH_3

Your answer

C

[1]

- 13 Standard electrode potentials for two redox systems are shown below.



What is the standard electrode potential for $\text{Cr}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cr}(\text{s})$?

- A -0.32V
- B -0.90V
- C -1.16V
- D -1.80V

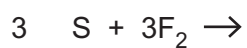
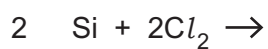
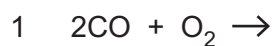
Your answer

B

[1]

14 The three reactions below each form one product only.

Which reaction(s) form(s) a product with non-polar molecules?



A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

A

[1]

15 Which ion(s) contain(s) one or more unpaired electrons?



A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

B

[1]

BLANK PAGE

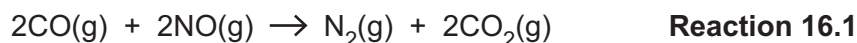
PLEASE DO NOT WRITE ON THIS PAGE

SECTION B

Answer **all** the questions.

- 16** A catalytic converter in a car removes nitrogen monoxide, NO, and carbon monoxide, CO, from the exhaust gases.

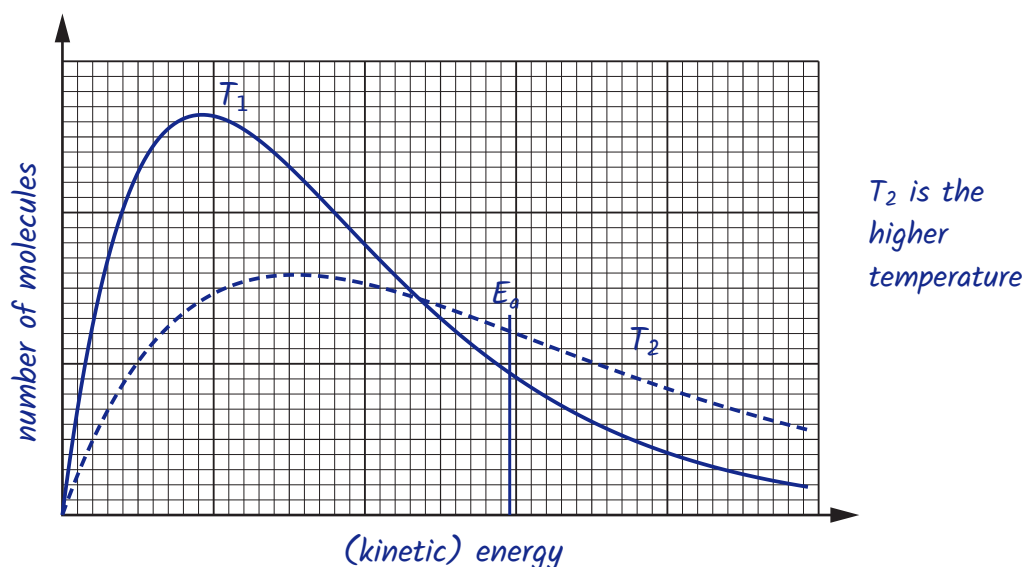
(a) One reaction that happens in a catalytic converter is shown below.



- (i) Explain how increasing the temperature increases the rate of **Reaction 16.1**.

Include a labelled sketch, using Boltzmann distributions, on the grid below.

Label the axes.



At a higher temperature the molecules have more kinetic energy, so the distribution shifts to the right with a lower peak.

More molecules have energy greater than or equal to the activation energy, E_a (greater area under the curve to the right of E_a), so more collisions are successful per unit time and the rate increases.

[3]

- (ii) The rate of **Reaction 16.1** is investigated by carrying out three experiments at the same temperature. The results are shown below.

Experiment	[NO(g)] /mol dm ⁻³	[CO(g)] /mol dm ⁻³	Initial rate /mol dm ⁻³ s ⁻¹
1	2.75×10^{-4}	7.25×10^{-4}	1.85×10^{-4}
2	5.50×10^{-4}	7.25×10^{-4}	7.40×10^{-4}
3	1.10×10^{-3}	2.90×10^{-3}	1.18×10^{-2}

Determine the orders with respect to NO and CO, the rate equation, and the rate constant, k , including units.

Explain your reasoning.

Expt 1 to 2: [NO] $\times 2$ with [CO] constant, rate $\times 4$ (1.85 to 7.40×10^{-4}), so the reaction is 2nd order with respect to NO.

Expt 2 to 3: [NO] $\times 2$ and [CO] $\times 4$, rate $\times 16$ (7.40×10^{-4} to 1.18×10^{-2}). Doubling [NO] gives $\times 4$, so quadrupling [CO] gives $\times 4$, so it is 1st order with respect to CO.

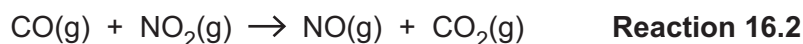
$$\text{rate} = k[\text{NO}]^2[\text{CO}]$$

$$k = \text{rate} \div ([\text{NO}]^2[\text{CO}]) = 1.85 \times 10^{-4} \div ((2.75 \times 10^{-4})^2 \times 7.25 \times 10^{-4}) = 3.37 \times 10^6$$

$$\text{units} = \text{mol dm}^{-3} \text{ s}^{-1} \div (\text{mol dm}^{-3})^3 = \text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$$

$$k = 3.37 \times 10^6 \text{ units } \text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1} \quad [5]$$

- (b) Carbon monoxide also reacts with nitrogen dioxide as shown in **Reaction 16.2**.



The rate equation for **Reaction 16.2** is shown below:

$$\text{rate} = k[\text{NO}_2\text{(g)}]^2$$

Suggest a possible two-step mechanism for **Reaction 16.2**.

The first step is much slower than the second step.



[2]

17 This question is about energy changes.

(a) Magnesium reacts with aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$ as shown below.



A student adds an excess of magnesium to 100.0 cm^3 of $0.400 \text{ mol dm}^{-3}$ $\text{AgNO}_3(\text{aq})$.
The initial temperature is 20.0°C .

- (i) Determine the maximum temperature reached in this reaction.
Give your answer to **3** significant figures.

Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

$$n(\text{AgNO}_3) = 0.400 \times 100.0 \div 1000 = 0.0400 \text{ mol}$$

$$\begin{aligned} &1 \text{ mol Mg reacts with 2 mol AgNO}_3, \text{ so energy released} \\ &= 678 \times 0.0400 \div 2 = 13.56 \text{ kJ} = 13\,560 \text{ J} \end{aligned}$$

$$q = mc\Delta T, \text{ so } \Delta T = 13\,560 \div (100.0 \times 4.18) = 32.4^\circ\text{C}$$

$$\text{maximum temperature} = 20.0 + 32.4 = 52.4^\circ\text{C}$$

maximum temperature reached = ...52.4..... $^\circ\text{C}$ [4]

- (ii) The student wants to repeat the experiment, but there is not enough $\text{AgNO}_3(\text{aq})$ left to use another 100.0 cm^3 portion.

The student decides to modify the method by adding an excess of magnesium to 50.0 cm^3 of $0.400\text{ mol dm}^{-3}\text{AgNO}_3(\text{aq})$.

Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

The maximum temperature would be the same (52.4 °C). Half the amount of AgNO_3 reacts, so half the energy is released, but it heats half the mass (volume) of solution, so ΔT is the same.

[1]

- (b) Nitric acid is manufactured from ammonia in a multi-stage process.
The equation for the first stage in this process is shown in **Reaction 17.1**.



Some standard enthalpy changes of formation are shown in the table.

Compound	$\Delta_f H^\ominus / \text{kJ mol}^{-1}$
$\text{NH}_3(\text{g})$	-46
$\text{H}_2\text{O}(\text{l})$	-286

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

The enthalpy change when 1 mole of a compound is formed from its elements in their standard states, under standard conditions.

[1]

- (ii) Calculate the standard enthalpy change of formation, $\Delta_f H^\ominus$, of $\text{NO}(\text{g})$.

$$\Delta H^\ominus = \Sigma \Delta_f H^\ominus(\text{products}) - \Sigma \Delta_f H^\ominus(\text{reactants})$$

$$-1172 = [4\Delta_f H^\ominus(\text{NO}) + 6(-286)] - 4(-46)$$

$$4\Delta_f H^\ominus(\text{NO}) = -1172 + 1716 - 184 = +360$$

$$\Delta_f H^\ominus(\text{NO}) = +360 \div 4 = +90 \text{ kJ mol}^{-1}$$

$$\Delta_f H^\ominus \text{ of NO(g)} = \dots\dots\dots +90 \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (c) Carbon disulfide, CS_2 , reacts with dinitrogen oxide, N_2O , as shown in **Reaction 17.2**.



Standard entropies, $S^\ominus$, are shown in the table.

Substance	$\text{CS}_2(\text{l})$	$\text{N}_2\text{O}(\text{g})$	$\text{S}_8(\text{s})$	$\text{CO}_2(\text{g})$	$\text{N}_2(\text{g})$
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	151	220	256	214	192

- (i) Explain the term **entropy**.

Entropy is a measure of the dispersal of energy in a system (the degree of disorder of the particles).

[1]

- (ii) The free energy change, ΔG , of **Reaction 17.2** is $-2672 \text{ kJ mol}^{-1}$ at 25°C .

Calculate the enthalpy change, ΔH , of **Reaction 17.2**, in kJ mol^{-1} .

$$\Delta S^\ominus = [256 + 4(214) + 8(192)] - [4(151) + 8(220)]$$

$$= 2648 - 2364 = +284 \text{ J K}^{-1} \text{mol}^{-1} = +0.284 \text{ kJ K}^{-1} \text{mol}^{-1}$$

$$T = 25 + 273 = 298 \text{ K}$$

$$\Delta G = \Delta H - T\Delta S, \text{ so } \Delta H = \Delta G + T\Delta S$$

$$\Delta H = -2672 + (298 \times 0.284) = -2672 + 84.6 = -2587 \text{ kJ mol}^{-1}$$

$$\Delta H = -2587 \text{ kJ mol}^{-1} \quad [3]$$

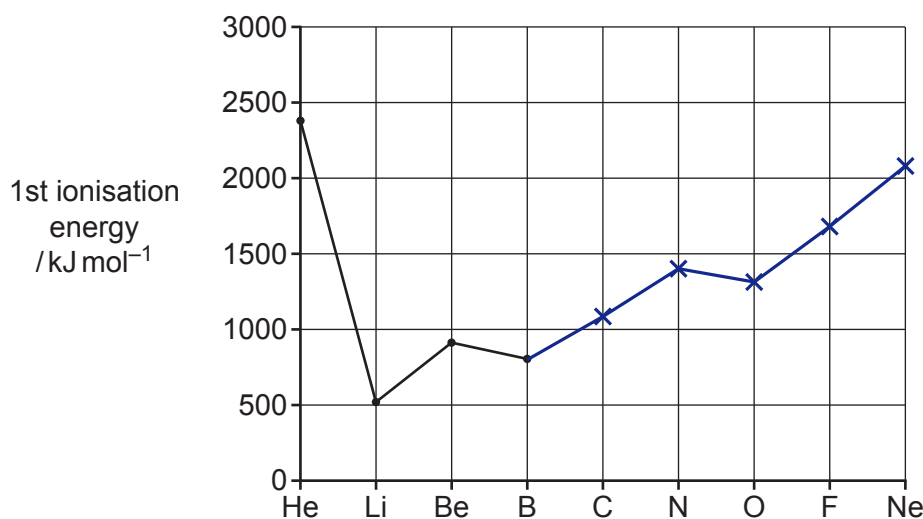
- (iii) A student concludes that **Reaction 17.2** is feasible at all temperatures.

Explain whether the student is correct or not.

The student is correct. ΔS is positive ($+284 \text{ J K}^{-1} \text{mol}^{-1}$) and ΔH is negative ($-2587 \text{ kJ mol}^{-1}$), so $-T\Delta S$ is always negative and $\Delta G = \Delta H - T\Delta S$ is negative at all temperatures, so the reaction is always feasible.

[2]

- 18 The graph shows the first ionisation energies for elements from helium, He, to boron, B, in the periodic table.



- (a) Complete the graph for C, N, O, F and Ne. [2]

- (b) Estimate the energy required to form **one** $\text{Li}^+(\text{g})$ ion from one $\text{Li}(\text{g})$ atom.

Give your answer in kJ, in standard form, and to **two** significant figures.

from the graph, IE of Li $\approx 500 \text{ kJ mol}^{-1}$

energy for one ion = $500 \div 6.02 \times 10^{23}$

energy = ... 8.3×10^{-22} kJ [1]

- (c) Explain why the first ionisation energies of He and Be are both higher than the first ionisation energy of Li.

Explanation for He: *He has fewer shells; its outer electrons are in the 1s shell, closer to the nucleus than the 2s electron of Li, with less shielding and a smaller atomic radius, so they experience a greater nuclear attraction.*

Explanation for Be: *Be has a greater nuclear charge (4 protons compared with 3) and its outer electrons are in the same shell (2s sub-shell) as Li, with similar shielding, so the outer electrons of Be are attracted more strongly to the nucleus.*

[4]

- (d) Explain why the first ionisation energy of Be is higher than the first ionisation energy of B.

The electron removed from B is in the 2p sub-shell, but the electron removed from Be is in the 2s sub-shell.

The 2p sub-shell is at a higher energy level than the 2s sub-shell, so the B electron is removed more easily. [2]

19 This question is about acids and buffer solutions.

- (a) Succinic acid, $\text{HOOC}(\text{CH}_2)_2\text{COOH}$, is a weak dibasic acid that is used in tablet form in health supplements.

A student plans to determine the mass of succinic acid in one tablet of a succinic acid health supplement.

The student carries out a titration with potassium hydroxide.

The end point occurs when both acidic protons in succinic acid have been replaced as shown in **Equation 19.1**.



The student uses the following method.

- Stage 1** The student crushes four tablets of the health supplement and dissolves the powdered tablets in distilled water.
- Stage 2** The student makes up the solution from **Stage 1** to 250.0 cm^3 in a volumetric flask.
- Stage 3** The student titrates 10.0 cm^3 portions of the solution obtained in **Stage 2** with $0.0600\text{ mol dm}^{-3}$ potassium hydroxide, using phenolphthalein as the indicator.

The student carries out a trial titration, followed by three further titrations. The results are shown below.

Titration	Trial	1	2	3
Final burette reading / cm^3	25.25	23.75	25.35	25.75
Initial burette reading / cm^3	2.50	1.30	2.65	3.20
Titre / cm^3	22.75	22.45	22.70	22.55

- (i) Complete the table and calculate the mean titre that the student should use for analysing the results.

concordant titres (within 0.10 cm^3): 22.45 and 22.55

mean = $(22.45 + 22.55) \div 2 = 22.50\text{ cm}^3$

mean titre = ...22.50..... cm^3 [2]

- (ii) Use the student's results and **Equation 19.1** to calculate the mass, in mg, of succinic acid in **one** tablet of the health supplement.

Give you answer to **3** significant figures.

$$n(\text{KOH}) = 0.0600 \times 22.50 \div 1000 = 1.35 \times 10^{-3} \text{ mol}$$

$$n(\text{acid}) \text{ in } 10.0 \text{ cm}^3 = 1.35 \times 10^{-3} \div 2 = 6.75 \times 10^{-4} \text{ mol}$$

$$n(\text{acid}) \text{ in } 250.0 \text{ cm}^3 = 6.75 \times 10^{-4} \times 25 = 0.016875 \text{ mol}$$

$$M(\text{HOOC}(\text{CH}_2)_2\text{COOH}) = 118.0 \text{ g mol}^{-1}$$

$$\text{mass in 4 tablets} = 0.016875 \times 118.0 = 1.99125 \text{ g}$$

$$\text{mass in 1 tablet} = 1.99125 \div 4 = 0.4978 \text{ g} = 498 \text{ mg}$$

mass = ...498..... mg [5]

- (b) Glycolic acid, HOCH_2COOH , ($\text{p}K_{\text{a}} = 3.83$) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of 0.750 mol dm^{-3} glycolic acid to 40.0 cm^3 of 0.625 mol dm^{-3} potassium hydroxide, KOH .

- (i) Explain why a buffer solution is formed.

Glycolic acid is in excess, so it is only partially neutralised: some HOCH_2COOH remains and potassium glycolate, $\text{HOCH}_2\text{COO}^-$ (the conjugate base), is formed. [1]

- (ii) Calculate the pH of the buffer solution that has been prepared.

Give your answer to **2** decimal places.

$$n(\text{HOCH}_2\text{COOH}) = 0.750 \times 60.0 \div 1000 = 0.0450 \text{ mol}$$

$$n(\text{KOH}) = 0.625 \times 40.0 \div 1000 = 0.0250 \text{ mol}$$

$$\text{in buffer: } n(\text{HOCH}_2\text{COOH}) = 0.0450 - 0.0250 = 0.0200 \text{ mol}$$

$$n(\text{HOCH}_2\text{COO}^-) = 0.0250 \text{ mol (total volume } 100.0 \text{ cm}^3)$$

$$[\text{HA}] = 0.200 \text{ mol dm}^{-3}, [\text{A}^-] = 0.250 \text{ mol dm}^{-3}$$

$$K_{\text{a}} = 10^{-3.83} = 1.479 \times 10^{-4} \text{ mol dm}^{-3}$$

$$[\text{H}^+] = K_{\text{a}} \times [\text{HA}] \div [\text{A}^-] = 1.479 \times 10^{-4} \times 0.200 \div 0.250$$

$$= 1.183 \times 10^{-4} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(1.183 \times 10^{-4}) = 3.93$$

$$\text{pH} = \dots\dots\dots 3.93 \dots\dots\dots [4]$$

- (iii) A small amount of aqueous ammonia, $\text{NH}_3(\text{aq})$, is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added $\text{NH}_3(\text{aq})$.

$\text{HOCH}_2\text{COOH} \rightleftharpoons \text{H}^+ + \text{HOCH}_2\text{COO}^-$
The added NH_3 acts as a base and reacts with H^+ ($\text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+$),
so $[\text{H}^+]$ decreases. The equilibrium shifts to the right, so more glycolic
acid dissociates to replace the H^+ and the pH stays almost constant. [2]

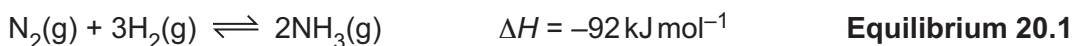
21
BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

20 This question is about equilibria involving hydrogen.

(a)* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.



1.20 mol $\text{N}_2(\text{g})$ is mixed with 3.60 mol $\text{H}_2(\text{g})$ in a 8.00 dm^3 container.

The mixture is heated to 550°C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3 .

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia. [6]

0.160 mol NH_3 forms, so 0.080 mol N_2 and 0.240 mol H_2 react.

At equilibrium: $n(\text{N}_2) = 1.20 - 0.080 = 1.12 \text{ mol}$; $n(\text{H}_2) = 3.60 - 0.240 = 3.36 \text{ mol}$; $n(\text{NH}_3) = 0.160 \text{ mol}$.

Concentrations: $[\text{N}_2] = 0.140$, $[\text{H}_2] = 0.420$, $[\text{NH}_3] = 0.0200 \text{ mol dm}^{-3}$.

$K_c = [\text{NH}_3]^2 \div ([\text{N}_2][\text{H}_2]^3) = 0.0200^2 \div (0.140 \times 0.420^3) = 0.0386 \text{ dm}^6 \text{ mol}^{-2}$

Temperature: the forward reaction is exothermic ($\Delta H = -92 \text{ kJ mol}^{-1}$), so a low temperature would give the maximum equilibrium yield. However, at a low temperature the rate is too slow, so industry uses a higher compromise temperature to give a fast enough rate.

Pressure: there are fewer moles of gas on the right (2 compared with 4), so a high pressure would give the maximum yield. However, a very high pressure is expensive to generate (energy and strong pipes) and is a safety hazard, so a lower compromise pressure is used.

Catalyst: the iron catalyst increases the rate without changing the equilibrium position, so a lower temperature can be used with a good yield, reducing energy costs.

Additional answer space if required.

.....

.....

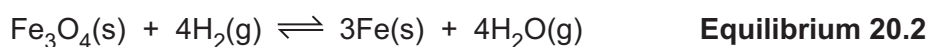
.....

.....

.....

- (b) In industry, hydrogen is also used to reduce the iron oxide Fe_3O_4 as shown in **Equilibrium 20.2**.

The reaction is carried out at 500°C .



- (i) When the temperature is decreased, the value of K_p decreases.

Determine whether the forward reaction is exothermic or endothermic.
Explain your answer.

Decreasing the temperature decreases K_p , so the equilibrium position shifts to the left (the backward reaction is favoured). Therefore the forward reaction is endothermic.

..... [1]

- (ii) Two students are discussing the effect of pressure on the equilibrium position of **Equilibrium 20.2**.

Student 1 says:

"There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side."

Student 2 disagrees.

Determine which student is correct. Justify your answer.

Student 2 is correct: there are the same number of moles of gas on each side (4 mol $\text{H}_2(\text{g})$ and 4 mol $\text{H}_2\text{O}(\text{g})$); solids are not counted, so pressure has no effect on the equilibrium position.

..... [1]

21 This question is about the reactions of Group 2 metals and their compounds.

- (a) A student adds magnesium to dilute hydrochloric acid in one test tube.
The student adds calcium to dilute hydrochloric acid in a second test tube.

A redox reaction takes place in each test tube.

- (i) Suggest **two** observations from the student's experiment that would show that calcium is more reactive than magnesium.

1 *Calcium fizzes (effervesces) faster, giving bubbles of gas more quickly.*

2 *Calcium dissolves (disappears) more quickly.*

[1]

- (ii) Write half-equations for the reaction of magnesium with hydrochloric acid.

Oxidation half-equation: *$Mg \rightarrow Mg^{2+} + 2e^{-}$*

Reduction half-equation: *$2H^{+} + 2e^{-} \rightarrow H_2$*

[2]

- (b) A sample of barium oxide is added to distilled water at 25 °C.
A colourless solution forms containing barium hydroxide, Ba(OH)₂.

The solution is made up to 250.0 cm³ with distilled water.
The pH of this solution is 13.12.

- (i) Determine the mass of barium oxide that was used.

Give your answer to **3** significant figures.

$$[H^{+}] = 10^{-13.12} = 7.59 \times 10^{-14} \text{ mol dm}^{-3}$$

$$[OH^{-}] = K_w \div [H^{+}] = 1.00 \times 10^{-14} \div 7.59 \times 10^{-14} = 0.1318 \text{ mol dm}^{-3}$$

$$n(OH^{-}) \text{ in } 250.0 \text{ cm}^3 = 0.1318 \times 250.0 \div 1000 = 0.03296 \text{ mol}$$

$$n(Ba(OH)_2) = n(BaO) = 0.03296 \div 2 = 0.01648 \text{ mol}$$

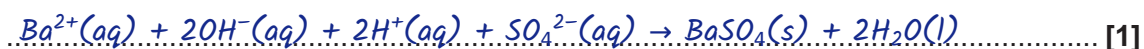
$$M(BaO) = 137.3 + 16.0 = 153.3 \text{ g mol}^{-1}$$

$$\text{mass} = 0.01648 \times 153.3 = 2.53 \text{ g}$$

mass of barium oxide = *2.53* g [5]

- (ii) 10 cm³ of dilute sulfuric acid is added to 10 cm³ of the colourless solution of Ba(OH)₂.

Write an ionic equation, including state symbols, for the reaction.



- (c) Limestone and huntite are two calcium minerals.

- (i) A typical sample of limestone contains 95.0% by mass of calcium carbonate, CaCO₃.

Fertiliser **Z**, Ca₅NH₄(NO₃)₁₁•10H₂O (*M_r* = 1080.5 g mol⁻¹) can be made from limestone.

Calculate the mass, in g, of limestone needed to make 1.50 kg of fertiliser **Z**.

Give your answer to **3** significant figures.

$$n(Z) = 1500 \div 1080.5 = 1.388 \text{ mol}$$

$$n(CaCO_3) = 5 \times 1.388 = 6.941 \text{ mol (5 Ca per formula unit)}$$

$$\text{mass } CaCO_3 = 6.941 \times 100.1 = 694.8 \text{ g}$$

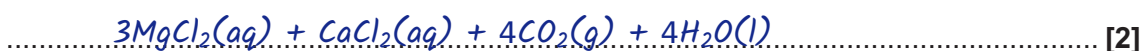
$$\text{mass of limestone} = 694.8 \times 100 \div 95.0 = 731 \text{ g}$$

mass of limestone = ... **731** g [3]

- (ii) Huntite is a carbonate mineral with the chemical formula Mg₃Ca(CO₃)₄.

Huntite reacts with dilute hydrochloric acid to produce bubbles of a gas and a colourless solution.

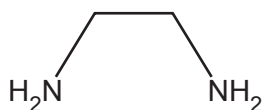
Construct the equation for the reaction. Include state symbols.



22 This question is about reactions of transition metal compounds.

(a) Ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is a bidentate ligand.

The structure of ethane-1,2-diamine is shown below.



(i) Explain why ethane-1,2-diamine can act as a bidentate ligand.

*Each N atom has a lone pair, so the molecule donates two electron pairs
to the metal ion, forming two coordinate (dative covalent) bonds.*

[1]

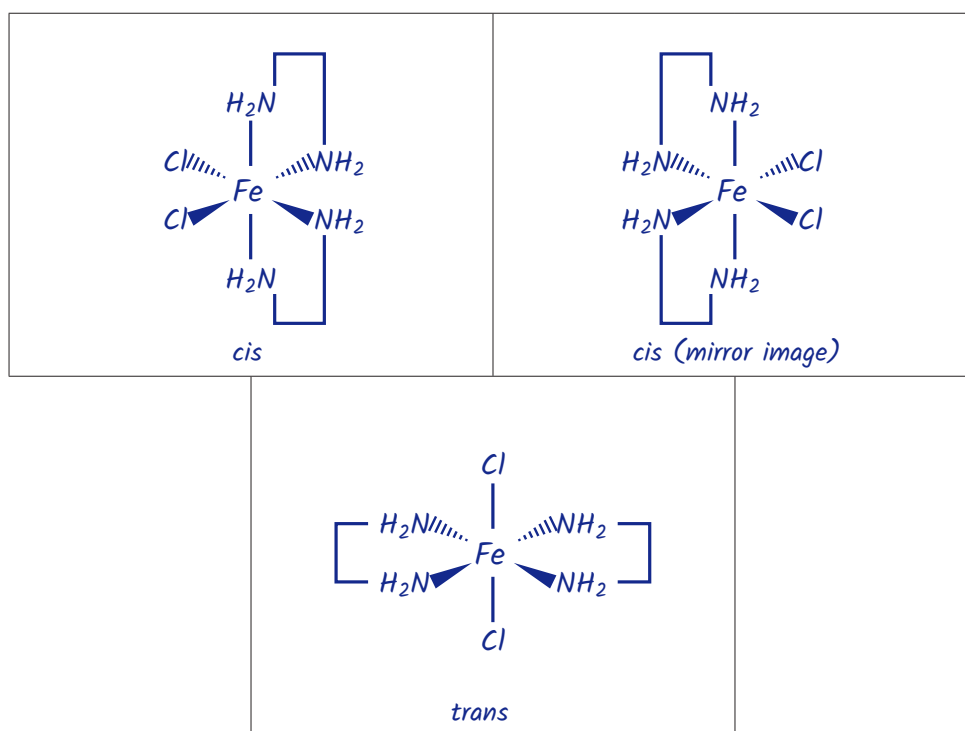
(ii) The iron(III) ion, Fe^{3+} , forms a complex ion **A** with two ethane-1,2-diamine ligands and two chloride ligands.

Complex ion **A** has *cis* and *trans* stereoisomers.
One of these stereoisomers exists as optical isomers.

Determine the empirical formula, with charge, of complex ion **A** and draw the 3-D structures of the three stereoisomers.

Empirical formula with charge *$[\text{FeC}_4\text{H}_{16}\text{N}_4\text{Cl}_2]^+$*

Structures



[4]

- (b) Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate. A pale green precipitate forms which turns brown when left to stand in air.

(i) Write an ionic equation for the formation of the pale green precipitate.



(ii) Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	E°/V
1	$\text{Fe}(\text{OH})_3(\text{s}) + \text{e}^{-} \rightleftharpoons \text{Fe}(\text{OH})_2(\text{s}) + \text{OH}^{-}(\text{aq})$	-0.56 V
2	$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^{-} \rightleftharpoons 4\text{OH}^{-}(\text{aq})$	+0.40 V

The brown precipitate is $\text{Fe}(\text{OH})_3$; $\text{Fe}(\text{OH})_2$ is oxidised by oxygen in the air (Fe^{2+} is oxidised to Fe^{3+}).

Redox system 1 has a more negative E° (-0.56 V) than redox system 2 (+0.40 V), so O_2 is the stronger oxidising agent. $E_{\text{cell}} = 0.40 - (-0.56) = +0.96 \text{ V}$, which is positive, so the reaction is feasible.

Redox system 1 shifts to the left ($\text{Fe}(\text{OH})_2$ loses electrons) and redox system 2 shifts to the right (O_2 gains electrons).



..... [4]

TURN OVER FOR QUESTION 22(c)

(c)* This question is about copper and copper compounds.

Experiment 1

Hydrochloric acid, $\text{HCl}(\text{aq})$, is added to an aqueous solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

A yellow-green solution forms containing complex ion **B**.

Experiment 2

A piece of copper metal is heated with concentrated sulfuric acid.

A reaction takes place forming a pale blue solution **C** and 45 cm^3 of a gas **D**, measured at RTP. The mass of gas **D** is 0.12 g.

Experiment 3

An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution **E**.

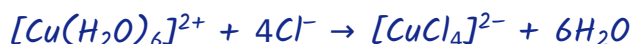
Aqueous potassium iodide, $\text{KI}(\text{aq})$, is added to the blue solution **E**.

A white precipitate **F** and a brown solution **G** form.

Determine the formulae of **B–G**.

Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate. [6]

Experiment 1: **B** is $[\text{CuCl}_4]^{2-}$ (ligand substitution, *Cu* stays +2):



Experiment 2: $n(\text{D}) = 45 \div 24\,000 = 1.875 \times 10^{-3} \text{ mol}$; $M(\text{D}) = 0.12 \div$

$1.875 \times 10^{-3} = 64 \text{ g mol}^{-1}$, so **D** is SO_2 . **C** is CuSO_4 (contains

$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$).

$\text{Cu} + 2\text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{SO}_2 + 2\text{H}_2\text{O}$; *Cu* is oxidised from 0 to +2 and *S* is

reduced from +6 to +4.

Experiment 3: **E** is $\text{Cu}(\text{NO}_3)_2$ (contains $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$): $\text{CuO} + 2\text{HNO}_3 \rightarrow$

$\text{Cu}(\text{NO}_3)_2 + \text{H}_2\text{O}$

F is CuI (white precipitate) and **G** is I_2 (brown solution): $2\text{Cu}^{2+} + 4\text{I}^- \rightarrow$

$2\text{CuI} + \text{I}_2$. *Cu* is reduced from +2 to +1 and *I* is oxidised from -1 to 0.

Additional answer space if required.

END OF QUESTION PAPER

[illegible]

Oxford Cambridge and RSA

Copyright Information

OCR is committed to seeking permission to reproduce all third-party content that it uses in its assessment materials. OCR has attempted to identify and contact all copyright holders whose work is used in this paper. To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced in the OCR Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download from our public website (www.ocr.org.uk) after the live examination series.

If OCR has unwittingly failed to correctly acknowledge or clear any third-party content in this assessment material, OCR will be happy to correct its mistake at the earliest possible opportunity.

For queries or further information please contact The OCR Copyright Team, The Triangle Building, Shaftesbury Road, Cambridge CB2 8EA.

OCR is part of Cambridge University Press & Assessment, which is itself a department of the University of Cambridge.